**State of California**
**The Resources Agency**
**Department of Water Resources**

# TIMING, THERMAL TOLERANCE RANGES, AND POTENTIAL WATER TEMPERATURE EFFECTS ON EMIGRATING JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER
# SP-F10 TASK 4B

## Oroville Facilities Relicensing
## FERC Project No. 2100

OCTOBER 2003

**GRAY DAVIS**
Governor
State of California

**MARY D. NICHOLS**
Secretary for Resources
The Resources Agency

**MICHAEL J. SPEAR**
Interim Director
Department of Water Resources

**State of California**
**The Resources Agency**
**Department of Water Resources**

# TIMING, THERMAL TOLERANCE RANGES, AND POTENTIAL WATER TEMPERATURE EFFECTS ON EMIGRATING JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER
# SPF10 TASK 4B

## Oroville Facilities Relicensing
## FERC Project No. 2100

**This report was prepared under the direction of**

Terry J. Mills........................................................Chief, Ecological Studies Branch, DWR

**by**

Paul Bratovich ................................................. Principal/Fisheries Technical Lead, SWRI
David Olson................................Senior Environmental Scientist/Project Manager, SWRI
Steve Pagliughi .....................................................Environmental Scientist/Author, SWRI
Adrian Pitts............................................................Environmental Scientist/Author, SWRI

**Assisted by**

Becky Fredlund ................................ Graphics/GIS Technician/Graphical Support, SWRI
Amanda O'Connell ............................ Environmental Planner/Technical Research, SWRI

# TABLE OF CONTENTS

1.0 SUMMARY ....................................................................... 1-1
2.0 PURPOSE ....................................................................... 2-1
3.0 BACKGROUND ....................................................................... 3-1
  3.1 Study Area ....................................................................... 3-1
  3.2 Description of Facilities ....................................................................... 3-2
  3.3 Current Operational Constraints ....................................................................... 3-5
    3.3.1 Downstream Operation ....................................................................... 3-5
      3.3.1.1 Instream Flow Requirements ....................................................................... 3-6
      3.3.1.2 Temperature Requirements ....................................................................... 3-6
      3.3.1.3 Water Diversions ....................................................................... 3-7
      3.3.1.4 Water Quality ....................................................................... 3-7
    3.3.2 Flood Management ....................................................................... 3-7
  3.4 Water Temperature Effects on Emigrating Salmonids ....................................................................... 3-8
  3.5 Life Histories and Emigration of Juvenile Salmonids in the Lower Feather River ....................................................................... 3-9
4.0 METHODOLOGY ....................................................................... 4-1
5.0 RESULTS AND DISCUSSION ....................................................................... 5-1
  5.1 Emigration Timing of Juvenile Salmonids in the Lower Feather River ....................................................................... 5-1
    5.1.1 Central Valley ESU Steelhead ....................................................................... 5-1
    5.1.2 Central Valley ESU Chinook Salmon ....................................................................... 5-4
  5.2 Analytical Time Periods for Emigrating Juvenile Steelhead in the Lower Feather River ....................................................................... 5-8
  5.3 Analytical Time Periods for Emigrating Juvenile Chinook Salmon in the Lower Feather River ....................................................................... 5-8
  5.4 Definition of water Temperature Indices for Emigrating Juvenile Steelhead ....................................................................... 5-8
  5.5 Definition of Water Temperature Indices for Emigrating Juvenile Chinook Salmon ....................................................................... 5-10
  5.6 Water Temperature in the Low Flow Channel of the Lower Feather River and Associated Effects to Emigrating Juvenile Salmonids ....................................................................... 5-13
    5.6.1 Central Valley ESU Steelhead ....................................................................... 5-13
    5.6.2 Central Valley ESU Chinook Salmon ....................................................................... 5-15
  5.7 Water Temperature in the High Flow Channel of the Lower Feather River and Associated Effects to Emigrating Juvenile Salmonids ....................................................................... 5-17
    5.7.1 Central Valley ESU Steelhead ....................................................................... 5-17
    5.7.2 Central Valley ESU Chinook Salmon ....................................................................... 5-19
6.0 CONCLUSIONS ....................................................................... 6-1
7.0 REFERENCES ....................................................................... 7-1

## APPENDICES

Appendix A -Emigrating Juvenile Steelhead and Juvenile Chinook Salmon Thermal Range Tolerances and Water Temperature Profiles in the Lower Feather River.

## LIST OF FIGURES

Figure 1-1. Water Temperature Data Logger Locations: Lower Feather River ........ 1-2
Figure 3.2-1. Oroville Facilities FERC Project Boundary ........ 3-3
Figure 5.1-1. Fish Survey Locations: Lower Feather River ........ 5-2
Figure 5.6-1. Steelhead Thermal Ranges and Water Temperature Profile Downstream from Diversion Dam - River Mile 67.4 ........ 5-14
Figure 5.6-2. Steelhead Thermal Ranges and Water Temperature Profile at the Spawning Channel - River Mile 66.2 ........ 5-15
Figure 5.6-3. Chinook Salmon Thermal Ranges and Water Temperature Profile at Auditorium Riffle - River Mile 66.2 ........ 5-16
Figure 5.6-4. Chinook Salmon Thermal Ranges and Water Temperature Profile Upstream from Afterbay Outlet - River Mile 59.4 ........ 5-16
Figure 5.7-1. Steelhead Thermal Ranges and Water Temperature Profile at Star Bend - River Mile 18.2 ........ 5-18
Figure 5.7-2. Steelhead Thermal Ranges and Water Temperature Profile at Mouth of Yuba River - River Mile 27.5 ........ 5-19
Figure 5.7-3. Chinook Salmon Thermal Ranges and Water Temperature Profile Downstream from Afterbay Outlet - River Mile 58.6 ........ 5-20
Figure 5.7-4. Chinook Salmon Thermal Ranges and Water Temperature Profile at Singh above Riviera Road - River Mile 45.9 ........ 5-21
Figure 5.7-5. Chinook Salmon Thermal Ranges and Water Temperature Profile at Mouth of Yuba River - River Mile 27.5 ........ 5-22

## 1.0. SUMMARY

Task 4B of SP-F10 was completed by conducting a literature review to determine the timing of emigration, the thermal tolerance ranges, and the potential effects of water temperatures on emigrating juvenile salmonids in the lower Feather River. Upon completion of the literature review, spatial and temporal water temperature distributions in the lower Feather River were determined. Water temperature distributions were then combined with emigration dates to determine the potential impacts to emigrating juvenile salmonids from thermal stress loading.

Juvenile steelhead in the lower Feather River have been reported to emigrate from approximately February through September, with peak emigration occurring from March through mid-April (DWR 2000, 2002b; DWR and BOR 2000). However, empirical and observational data suggest that juvenile steelhead potentially emigrate during all months of the year in the lower Feather River. To evaluate potential project effects on emigrating juvenile steelhead, three thermal tolerance indices were established as: (1) less than or equal to 55$^{o}$ F (12.8$^{o}$ C); (2) more than 55$^{o}$ F and less than or equal to 65$^{o}$ F (18.3$^{o}$ C); and (3) more than 65$^{o}$ F, which were generally defined as suitable, potential sub-lethal effects, and unsuitable, respectively.

In the Low Flow Channel (LFC), from RM 67.4 (Diversion Dam) to RM 66.0 (**Figure 1-1**), mean daily water temperatures, during the defined emigration period, generally remained within the defined juvenile steelhead suitable index range ($\leq$55$^{o}$ F) from February through May, and late August through early September. Mean daily water temperatures for the remainder of the LFC (RM 64.1 to 59.4), during the defined emigration period, generally remained within the defined suitable index range from February through March. Mean daily water temperatures, throughout the LFC (RM 67.4 to RM 59.4) generally remained below 65$^{o}$ F year-round. At Robinson Riffle (RM 61.7), mean daily water temperatures exceeded 65$^{o}$ F once on June 19, 2002. In the High Flow Channel (RM 58.8 to RM 0.3), during the defined emigration period, mean daily water temperatures generally remained within the defined suitable index range from February through early March. Mean daily water temperatures from RM 58.8 to RM 41.8, during the defined emigration period, generally remained below the defined index value of 65$^{o}$ F from February through May and September, and sporadically from June through July. Mean daily water temperatures at the mouth of the Yuba River (RM 27.5), during the defined emigration period, generally remained below 65$^{o}$ F from February through August. Mean daily water temperatures for the remainder of the HFC (RM 25.2 to RM 0.3), during the defined emigration period, remained below 65$^{o}$ F from February through mid-May. Juvenile steelhead potentially emigrate year-round, so a brief summary of water temperatures in the lower Feather River from October through January is provided. In the LFC (RM 67.4 to RM 59.4), mean daily water temperatures generally remained within the defined suitable index range from mid-November through January and remained below 65$^{o}$ F year-round.

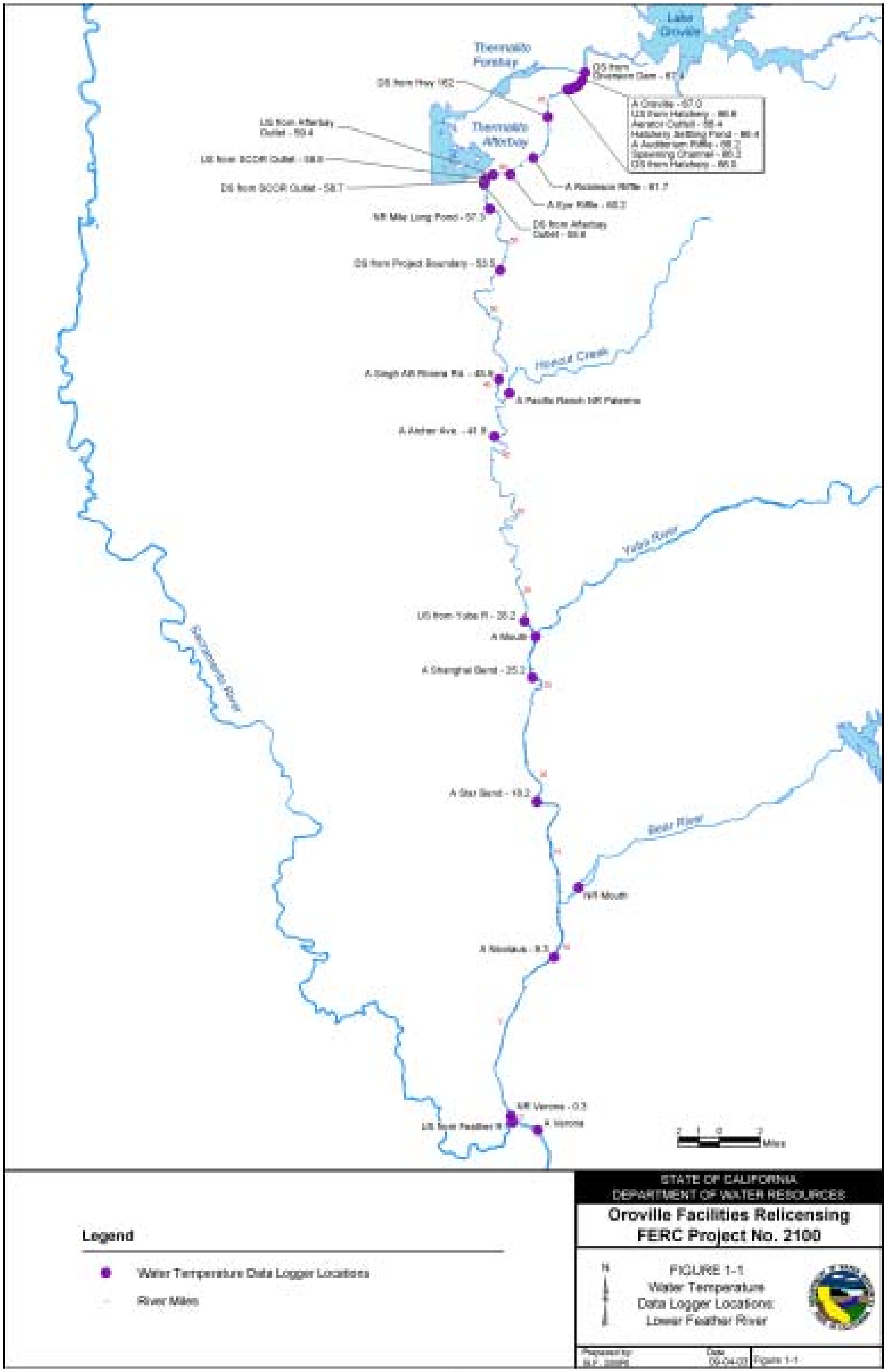


**Figure 1-1. Water Temperature Data Logger Locations: Lower Feather River**

Juvenile Chinook salmon in the lower Feather River have been reported to emigrate from approximately mid-November through June, with peak emigration occurring from January through March (Painter 1977; DWR 2002a, b; Cavallo 2003). For this evaluation, thermal tolerance indices for emigrating juvenile Chinook salmon were established as: (1) less than or equal to 62.6° F (17° C); (2) more than 62.6° F and less than or equal to 68° F (20° C); and (3) more than 68° F, which were generally defined as suitable, potentially sub-lethal effects, and unsuitable (upper incipient lethal effects), respectively.

In the LFC, from RM 67.4 (Diversion Dam) to RM 64.1 (Figure 1-1), mean daily water temperatures, during the defined emigration period for juvenile Chinook salmon, generally remained within the defined suitable index range (≤62.6° F) year-round. Mean daily water temperatures In the LFC (RM 67.4 to 59.4) did not exceed the defined index value of 68° F. Water temperatures in the LFC remained within the suitable index range during the reported peak of emigration (January through March) when, based on rotary screw trap data (DWR 2002b), approximately 96% of juvenile Chinook salmon emigrate. In the HFC, during the reported peak of juvenile Chinook salmon emigration, available water temperature data indicates that water temperatures did not exceed the defined suitable index range.

Elevated water temperatures in the lower Feather River may affect emigrating juvenile steelhead more than emigrating juvenile Chinook salmon. Water temperatures in the LFC are more conducive to emigrating salmonids than are water temperatures in the HFC. However, the projects' ability to manipulate water temperature through flow releases decreases with downstream distance from Oroville Dam. In the HFC during the warmest months of the year, cold water inflow from the Yuba River may provide localized thermal refugia.

# 2.0. PURPOSE

The purpose of Task 4B of Study Plan (SP)-F10 is to describe the relationship between water temperature and juvenile salmonid emigration patterns, and evaluate potential project effects on juvenile salmonid emigration in the Feather River downstream from the Fish Barrier Dam. Salmonids present in the Feather River include the Central Valley (CV) Evolutionarily Significant Unit (ESU) spring-run Chinook salmon (*Oncorhynchus tshawytscha*), the CV ESU fall-run Chinook salmon, and the CV ESU steelhead (*Oncorhynchus mykiss*). On September 16, 1999, naturally-spawned CV ESU spring-run Chinook salmon were listed as threatened under the federal Endangered Species Act (ESA) by the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) (NOAA 1999). The CV spring-run Chinook salmon ESU includes all naturally-spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, which includes naturally-spawned spring-run Chinook salmon in the Feather River (NOAA 1999). On March 19, 1998, naturally-spawned CV ESU steelhead were listed as threatened under the federal Endangered Species Act (ESA) by NOAA Fisheries (NOAA 1998). The CV steelhead ESU includes all naturally-spawned populations of steelhead in the Sacramento and San Joaquin Rivers and their tributaries, which includes naturally-spawned steelhead in the Feather River (NOAA 1998). The results and recommendations from this study fulfill, in part, statutory and regulatory requirements mandated by the ESA as it pertains to CV spring-run Chinook salmon and CV steelhead.

In addition to the ESA, Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (Code of Federal Regulations 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact from on-going and future operations. As a subtask of SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam*, Task 4B fulfills a portion of the FERC application requirements by describing the relationship between water temperature and juvenile salmonid emigration patterns, and evaluating the potential project effects on juvenile salmonid emigration in the Feather River downstream from the Fish Barrier Dam. In addition to fulfilling statutory requirements, the conclusions from this analysis may be used as the basis for developing or evaluating potential Resource Actions focused on providing appropriate water temperature regimes in the Feather River for emigrating juvenile salmonids.

Performing this subtask is necessary, in part, because operations of the Oroville Facilities affect Feather River flows which, in turn, directly influence in-river water temperature regimes. The Oroville Facilities regulate flow and water temperature below Oroville Dam (DWR 2001). Flow and water temperature manipulations resulting from operation of the Oroville Facilities may affect emigration of juvenile salmonids in the Feather River.

Ongoing operation of the Oroville Facilities influences flows and water temperatures in the Feather River downstream of the Thermalito Diversion Dam. Water temperature and flow are important factors influencing the emigration of juvenile salmonids in the lower Feather River. Task 4 of SP-F10 evaluates project effects on emigration of juvenile salmonids in the lower Feather River. Task 4A evaluates potential project effects on juvenile salmonid emigration by describing the relationship between flow and juvenile salmonid emigration patterns. Task 4B, herein, evaluates potential project effects on juvenile salmonid emigration by describing the relationship between water temperature and juvenile salmonid emigration patterns. For further description of Task 4B, see SP-F10 and associated interim and final reports.

# 3.0. BACKGROUND

## 3.1. STUDY AREA

The study area in which the results of Task 4B of SP-F10 apply includes the reach of the lower Feather River extending from the Fish Barrier Dam downstream to the confluence with the Sacramento River (Figure 1-1). This is the geographic range within the lower Feather River that encompasses areas through which juvenile salmonids emigrate. There are two distinct reaches within the study area: the upstream reach and the downstream reach. The upstream reach, typically referred to as the Low Flow Channel (LFC), extends from the Fish Barrier Dam at river mile (RM) 67.25 downstream to the Thermalito Afterbay Outlet at RM 59. The downstream reach, typically referred to as the High Flow Channel (HFC), extends from the Thermalito Afterbay Outlet downstream to the confluence with the Sacramento River at RM 0. The flow and water temperature regimes associated with each of these reaches are distinct, and are summarized below.

Minimum flows in the lower Feather River were established in the August 1983 agreement between the California Department of Water Resources (DWR) and the California Department of Fish and Game (DFG) (DWR 1983). The agreement established criteria for flow and water temperature in both the LFC and HFC reaches. The agreement also specified that DWR release a minimum of 600 cubic feet per second (cfs) into the Feather River from the Thermalito Diversion Dam for fisheries purposes. Therefore, the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet is operated at approximately 600 cfs year-round, with variations in flow occurring infrequently. Most flow deviations from 600 cfs occur during flood control releases, in the summer to satisfy downstream temperature requirements for salmonids, or for maintenance and monitoring purposes. Water temperatures in the LFC of the lower Feather River are typically lower than temperatures in the HFC, because the upstream reach of the Feather River is supplied directly by water taken from Lake Oroville's hypolimnion in order to meet Feather River Hatchery and other downstream water temperature requirements.

Unlike the relatively constant flow regime in the LFC of the lower Feather River, the flow regime in the HFC of the lower Feather River varies depending on runoff and month. The HFC reach extends from the Thermalito Afterbay Outlet (RM 59) to the confluence with the Sacramento River (RM 0). Minimum flow requirements in the HFC of the lower Feather River range from 1,000 to 1,700 cfs (DWR 1983), depending upon the percentage of normal runoff and the month. Although the minimum flow requirements range from 1,000 to 1,700 cfs, flow in the HFC typically ranges from the minimum flow requirement up to 7,500 cfs (DWR 1982). Flow in the HFC is, therefore, more varied than flow in the LFC. Flow in the HFC is additionally influenced by small flow contributions from Honcut Creek (RM 44) and the Bear River (RM 13), and by larger flow contributions from the Yuba River (RM 29). Water temperature in the HFC of the lower Feather River is typically warmer than water temperature in the LFC of the lower Feather River. Water temperature in the HFC is directly influenced by water releases from the Thermalito Afterbay Outlet. Because the Thermalito Afterbay is a large, shallow, warming basin, water released from the Thermalito Afterbay Outlet is typically warmer than the water originating from the LFC of the main channel of the lower Feather River. Typically, the contribution to the total flow in the Feather River from the Thermalito Afterbay Outlet is greater than flow contribution from the LFC of the lower Feather River. Water temperatures in the river downstream of the Thermalito Afterbay Outlet are generally warmer than water temperatures in the reach upstream of the Thermalito Afterbay Outlet. The ability of the Oroville operations to control or influence water temperature and its downstream extent under varying flow regimes and environmental conditions is being evaluated in study plans SP-E1, SP-E6, and SP-E7.

For the purpose of this analysis, the study area has been divided into two major reaches: (1) the LFC from the Fish Barrier Dam to the Thermalito Afterbay Outlet; and (2) the HFC from the Thermalito Afterbay Outlet to the mouth of the Feather River at its confluence with the Sacramento River.

## 3.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on **Figure 3.2-1**. The Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (maf) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of

Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

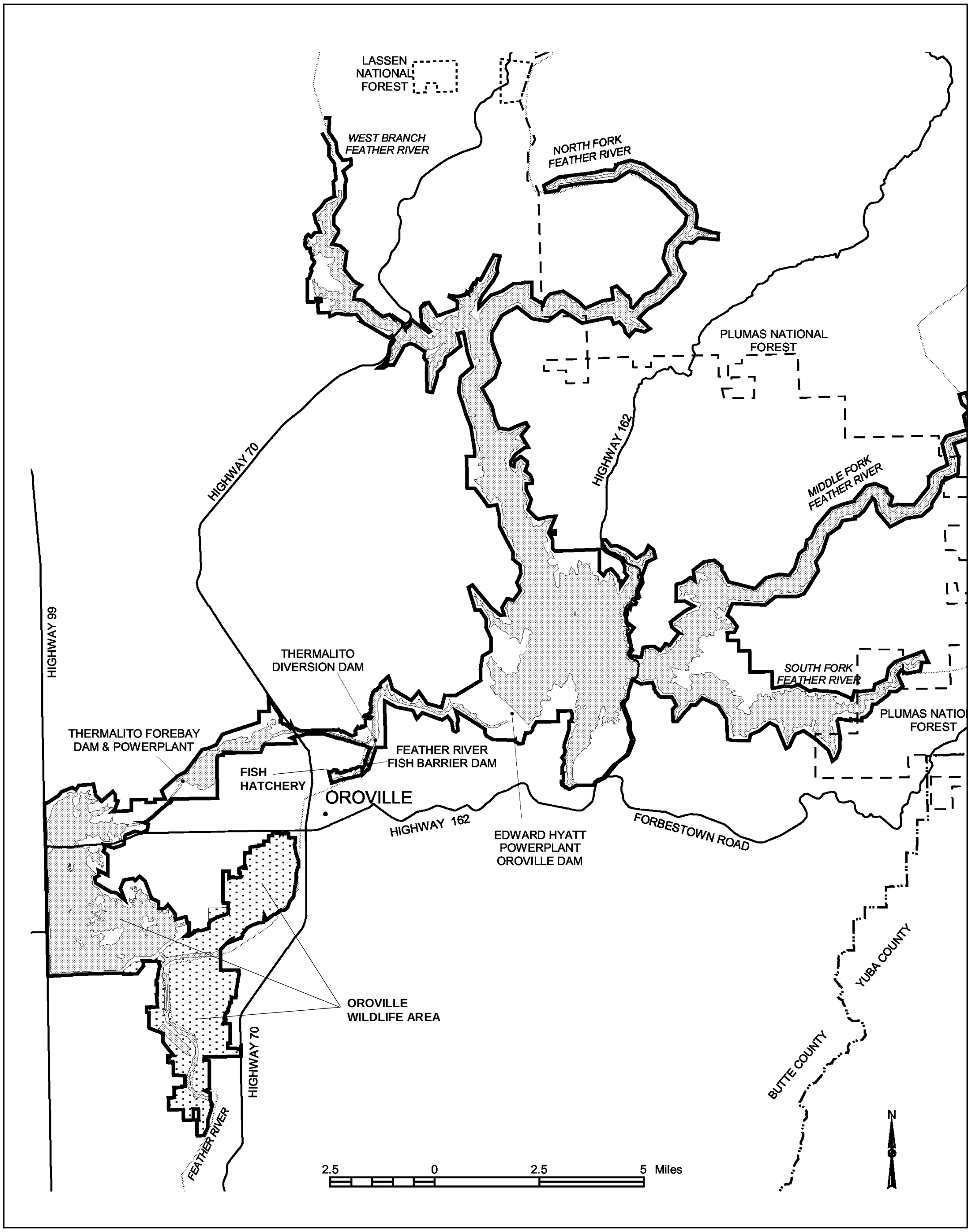


**Figure 3.2-1. Oroville Facilities FERC Project Boundary**

Thermalito Diversion Dam, four miles downstream of the Oroville Dam, creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate an average of 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000-acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

## 3.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected or requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

### <u>3.3.1 Downstream Operation</u>

An August 1983 agreement between DWR and DFG titled, "*Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife*," sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

#### *3.3.1.1 Instream Flow Requirements*

The Oroville Facilities are operated to meet minimum flows in the lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

#### *3.3.1.2 Temperature Requirements*

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for the objectives extending from April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook salmon. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook salmon and steelhead as a reasonable and prudent measure, DWR is required to maintain daily average water temperature of < 65° F at Feather River Mile 61.6 (Robinson Riffle in the low flow channel) from June 1 through September 30. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

#### *3.3.1.3 Water Diversions*

Monthly irrigation diversions of up to 190,000 (July 2002) af are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

#### *3.3.1.4 Water Quality*

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

### 3.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake

Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

## 3.4 WATER TEMPERATURE EFFECTS ON EMIGRATING SALMONIDS

Factors reported to have adversely affected salmonid stocks of the Central Valley include water diversion and water management, entrainment, dams and other structures, bank protection, dredging and sediment disposal, gravel mining, invasive aquatic organisms, fishery management practices, and contaminants (McEwan 2001). Many of these activities have affected the geomorphology and hydrology of rivers within the Sacramento - San Joaquin system, which have altered the temporal and spatial thermal regimes of the system. Acute and chronic elevated water temperatures are more of a concern in the Sacramento - San Joaquin system than are extremes in cold water temperatures. Water temperature affects every life stage of salmonids. Many of the physiological and behavioral processes associated with emigrating salmonids are, to some degree, water temperature dependant. Thermal tolerances are a function of exposure times and acclimation temperatures (Brett 1952). Fish acclimated at higher water temperatures tend to exhibit increased tolerance of higher water temperatures than fish acclimated to cooler water temperatures. Water temperature can influence many aspects of the life history of juvenile salmonids including growth rates, susceptibility to disease, and smoltification. All of these factors ultimately influence survivability.

It is difficult to isolate the effects of water temperature on emigrating juvenile salmonids because temperature is only one of many factors that synergistically influence the survivability of juvenile salmonids. Thermal stress loading occurs when water temperatures are outside suitable ranges which, by itself, can cause immediate or delayed mortalities (Brett 1952). However, adverse effects related to water temperature are often secondary in nature. It has been reported that successful emigration is positively correlated with body length. Growth is a function of temperature. If water temperatures are not optimal for growth, a decrease in the survivability of emigrating juvenile salmonids may occur (Folmar et al. 1982). Hoar (1976) stated that salmonids show a sharp increase in salinity resistance during the springtime, the magnitude of which depends on size, and is greater in the larger and more rapidly growing individuals. Water temperatures can also influence disease-causing organisms.

Salmonids are susceptible to a variety of diseases, each of which typically has water temperature ranges at which virulence is highest. While certain diseases are more prevalent in cold water, most of the more important diseases afflicting salmonids increase in virulence and severity as water temperatures increase (Boles et al. 1988; Materna 2001). In addition to water temperature effects on growth and disease, water temperature effects on homeostatic processes, in particular smoltification, also influence successful emigration. Smoltification is the physiological process that enables juvenile salmonids to transition from living in freshwater to saltwater. These physiological changes take place during seaward emigration. The smoltification process is sequential through time, designed to peak when emigrators reach saltwater. Elevated water temperatures have been shown to alter the timing and key physiological mechanisms associated with smoltification (Marine 1997). Wagner (1974) concluded that steelhead exposed to elevated water temperatures completed the physiological changes sooner than those exposed to colder water. In aquatic systems where historic water temperature regimes have increased due to disturbance activities, the synchronization of emigration timing and hypo-osmoregulation may be altered, resulting in emigrating juvenile salmonids reaching peak hypo-osmoregulatory capability prior to reaching saltwater, with a reversal of the smoltification process (desmoltification). The ramifications of desmoltification are a decreased ability to live in saltwater and higher mortality of emigrating juvenile salmonids. An important component of smoltification is an increase in gill ATPase activity that increases the hypo-osmoregulatory capabilities in emigrating juvenile salmonids. Elevated water temperature has been reported to inhibit gill ATPase activity (Marine 1997; Zaugg and Wagner 1973). Inhibition of gill ATPase activity reduces saltwater tolerance, potentially decreasing survivability and increasing mortality rates.

## 3.5. LIFE HISTORIES AND EMIGRATION OF JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER

Eggs from adult Chinook salmon and steelhead are deposited in appropriate gravel beds and, after incubation, embryos hatch to live as alevin (sac-fry) within interstitial spaces of gravel substrates. The length of time alevins reside in gravel substrates varies, but usually lasts until the yolk sac is fully absorbed (Moyle 2002). Young Chinook salmon and steelhead are referred to as fry upon emergence from gravel beds. During the transition from fry to parr, juvenile salmonids grow in size and spend more time utilizing deeper and higher velocity habitats for feeding and rearing (Moyle 2002). The parr-smolt transformation involves morphological, physiological, and behavioral changes. In general, these changes gradually occur while juvenile salmonids are en-route from natal streams to the ocean. Among the many morphological changes that take place, the external body silvering, change in body shape, and darkening of fin margins are the most widely used visual cues separating parr from smolt (Hoar 1976; Wedemeyer et al. 1980). However, it is the physiological changes that truly separate the two life stages. Smoltification, or the parr-smolt transformation, is the process by which juvenile salmonids undergo physiological changes necessary to successfully transition from a freshwater to a saltwater environment. Therefore, a true smolt has begun physiological change. These physiological changes include an increase in gill ATPase activity, decrease in condition in association with a decrease in total body lipids, decrease in nitrogen protein, and a loss of glycogen from the liver (Beckman et al. 2000; Hoar 1988; Zaugg and Wagner 1973). Behavioral changes that take place during smoltification include an increase in migratory behavior, and a stronger tendency to school and swim at mid-depth (Kalleberg 1958). Pinder and Eales (1969) reported that smolts maintained larger volumes of air in their swim bladder than parr, causing greater buoyancy (Pinder and Eales 1969). Wedemeyer et al. (1980) suggested increased buoyancy could make it difficult for juvenile salmonids to maintain residence at or near the river bottom, which may facilitate downstream migration (Wedemeyer et al. 1980). Saunders (1965) suggested that increased buoyancy during smoltification is likely a response in preparation for pelagic existence in the ocean, as opposed to bottom dwelling in rivers (Saunders 1965). Factors associated with initiation and progression of smoltification include water temperature, photoperiod, and flow (Adams et al. 1973; Berggren and Filardo 1993; Zaugg and Wagner 1973). Smoltification, and the associated changes occurring during this life stage, is often associated with an increased tendency for downstream migration behavior.

Emigration can be defined as the downstream movement, or migration, of juvenile salmonids. The term emigration is used broadly to describe short and long distance movements in association with habitat utilization, as well as to describe true seaward migrations. Within the context of this report, emigration refers to general downstream movements of juvenile salmonids without reference to purpose or extent of movement, unless otherwise stated.

Various historical monitoring data pertain to the emigration of juvenile salmonids in the lower Feather River. Painter et al. (1977) sampled juvenile Chinook salmon using fyke nets at Live Oak (RM 42). Length at capture, date of capture, and weekly mean catch per fyke net day were reported. DWR conducted seining surveys in the lower Feather River between January 1997 and August 2001 to document fish distribution and abundance (DWR 2002a). Sampling sites were located between the Fish Barrier Dam (RM 67.25) and Boyd's Pump (RM 23). Data were pooled for all sample sites. Length at capture and numbers captured by year and month were reported for juvenile Chinook salmon and steelhead. The total catch by species was also reported for each year in the LFC and the HFC. Although seining surveys provide information regarding the relative abundance, distribution, and size of juvenile Chinook salmon and steelhead, seining is not designed specifically to assess the characteristics of emigration. Consequently, seining data provides information about both rearing and emigrating juvenile salmonids.

From December 1998 through June 2001, DWR sampled juvenile salmonids in the lower Feather River using two rotary screw fish traps (RST) in order to assess the timing and general abundance of emigrating juvenile Chinook salmon, steelhead and other fish species (DWR 2002b). One RST (the Thermalito RST) was stationed at RM 60.1, just upstream of the Thermalito Afterbay Outlet, and the second RST (the Live Oak RST) was stationed at RM 42, just downstream of the confluence with Honcut Creek. Results were reported separately for each RST and included size-based separation, using daily fork length tables (Greene 1992), of fall-run and spring-run Chinook salmon, and steelhead. Results from RST sampling utilized in this task include the number of fish caught for each sample day and month, and length at capture.

Rotary screw trap data suggest most downstream movement of juvenile salmonids occurs at night in faster, deeper sections of rivers (DWR 2002b). During the day, nearshore habitat is utilized for resting, protection, and feeding. Thus, a variety of microhabitat types are utilized by emigrating juvenile salmonids. It is possible that temperature regimes vary according to microhabitat type. Interim report SP-F10, Task 1E, Section 3.4 "*Thermal Stratification*" addressed the potential for thermal stratification in the lower Feather River. Based on the summary of Section 3.4, it is unlikely that thermal stratification occurs in the vertical stratum of the lower Feather River. Therefore, water temperature variation between microhabitat types will not be addressed separately in this report. As noted in Section 3.1 of this report, a longitudinal water temperature gradient exists in the lower Feather River, primarily between the LFC (Fish Barrier Dam at RM 67.25 downstream to the Thermalito Afterbay Outlet at RM 59) and the HFC (Thermalito Afterbay Outlet downstream to the confluence with the Sacramento River at RM 0). The effects of water temperature on emigrating juvenile salmonids is evaluated separately for each of these reaches.

# 4.0. METHODOLOGY

The purpose of Task 4B of SP-F10 is to describe the relationship between water temperature and juvenile salmonid emigration patterns, and to evaluate potential project effects on juvenile salmonid emigration in the Feather River downstream from the Fish Barrier Dam. A literature review was conducted to determine the timing and duration of emigration for juvenile steelhead and juvenile Chinook salmon in the lower Feather River, and how water temperature affects emigrating juvenile salmonids. Many publications are available that make statements or cite other papers concerning juvenile salmonid thermal tolerances. Evaluation of these citings and statements revealed, in many instances, that there were no studies or data with which to confirm the reported values. These types of information sources were not used for this report in determining the thermal tolerances of emigrating juvenile salmonids in the lower Feather River. Primary data sources, usually from peer-reviewed journals that presented data allowing objective interpretations, were used to delineate thermal tolerance characteristics.

Water temperature data from the lower Feather River was obtained from DWR. A total of 24 water temperature logging stations were placed in the lower Feather River from RM 67.4 (Diversion Dam) to the confluence with the Sacramento River at RM 0 (Figure 1-1). A total of 11 water temperature logging stations were placed in the LFC of the lower Feather River. The most upstream logging station was located at river mile (RM) 67.4 and the most downstream logging station was located at RM 59.4. A total of 13 water temperature logging stations were placed in the HFC of the lower Feather River. The most upstream logging station was located at river mile (RM) 58.8 and the most downstream logging station was located at RM 0.3. Water temperatures were recorded from March 26, 2002 through April 17, 2003. A minimum of 96 data points was collected, at even intervals, during each 24-hour period from each water temperature logging station. Minimum, maximum, and mean water temperatures were determined for each diel cycle. In certain instances, water temperature data were unavailable and/or sample dates were inconsistent because of dewatered logging stations, loss of optics, vandalism, or malfunction. A complete description of the methodology associated with water temperature data collection can be found in Section 7.0, SP-W6 *Project Effects on Temperature Regime* of the Preliminary Draft Study Plan Package (DWR 2002c). For each water temperature logging station, figures were constructed showing temporal water temperature profiles and the associated salmonid thermal tolerance index categories.

Comparison of water temperature data to the thermal tolerance indices outlined for emigrating juvenile steelhead and juvenile Chinook salmon allowed evaluation of past river water temperature profiles, identification of time periods and river sections where thermal stress may occur, and provided the information necessary to support potential future Resource Action recommendations. The effects of water temperature on emigrating juvenile salmonids were analyzed separately for the LFC and the HFC, because a longitudinal water temperature gradient exists between these two reaches.

# 5.0. RESULTS AND DISCUSSION

## 5.1. EMIGRATION TIMING OF JUVENILE SALMONIDS IN THE LOWER FEATHER RIVER

### 5.1.1. Central Valley ESU Steelhead

DWR conducted seining surveys in the lower Feather River between January 1997 and August 2001 to document fish distribution and abundance (DWR 2002a). Sampling sites were located between the Fish Barrier Dam (RM 67.25) and Boyd's Pump (RM 23) (**Figure 5.1-1** and Figure 1-1). The study area included two sections, the Low Flow Channel (LFC) from the Fish Barrier Dam to the Thermalito Afterbay Outlet (RM 59), and the portion of the High Flow Channel (HFC) from Thermalito Afterbay Outlet to Boyd's Pump. Total catch data were pooled and reported within each section, while length frequency distribution data were pooled and reported for the entire sample area. Only data for 1999, 2000, and 2001 were reported because these years represented complete sampling seasons. Catch data were reported from March through August for each sampling season. Fork length (mm) was measured for the first 50 individuals captured. In 1999, 2000, and 2001 the percentage of steelhead measuring $\leq$50 mm was approximately 69%, 56%, and 65%, respectively. When sample sizes for measured steelhead were combined for all three sample years, approximately 62% of steelhead measured $\leq$50 mm. When total catch was combined for the three sample years, approximately 92% of juvenile steelhead were sampled from the LFC. Peak catches occurred in June of 1999, May of 2000, and March of 2001.

From December 1998 through June 2001, DWR sampled juvenile salmonids in the lower Feather River using two rotary screw fish traps (RST) in order to assess the timing and general abundance of emigrating juvenile Chinook salmon, steelhead and other fish species (DWR 2002b). The Thermalito RST was stationed at RM 60.1 and the Live Oak RST was stationed at RM 42 (Figure 5.1-1). During the three years of this study, a total of 1,551 juvenile steelhead were captured, primarily from February through June. In 1999, 2000, and 2001 the percentage of steelhead measuring $<$30 mm was 93%, 96%, and 93%, respectively. In 2000 and 2001, the average size was 25.5 (+/- 5.0 SD) mm at Thermalito and 88.9 (+/- 81.8 SD) mm at Live Oak. Only 1%, 2%, and 2% of all juvenile steelhead captured in 1999, 2000 and 2001, respectively, were captured in the Live Oak RST.

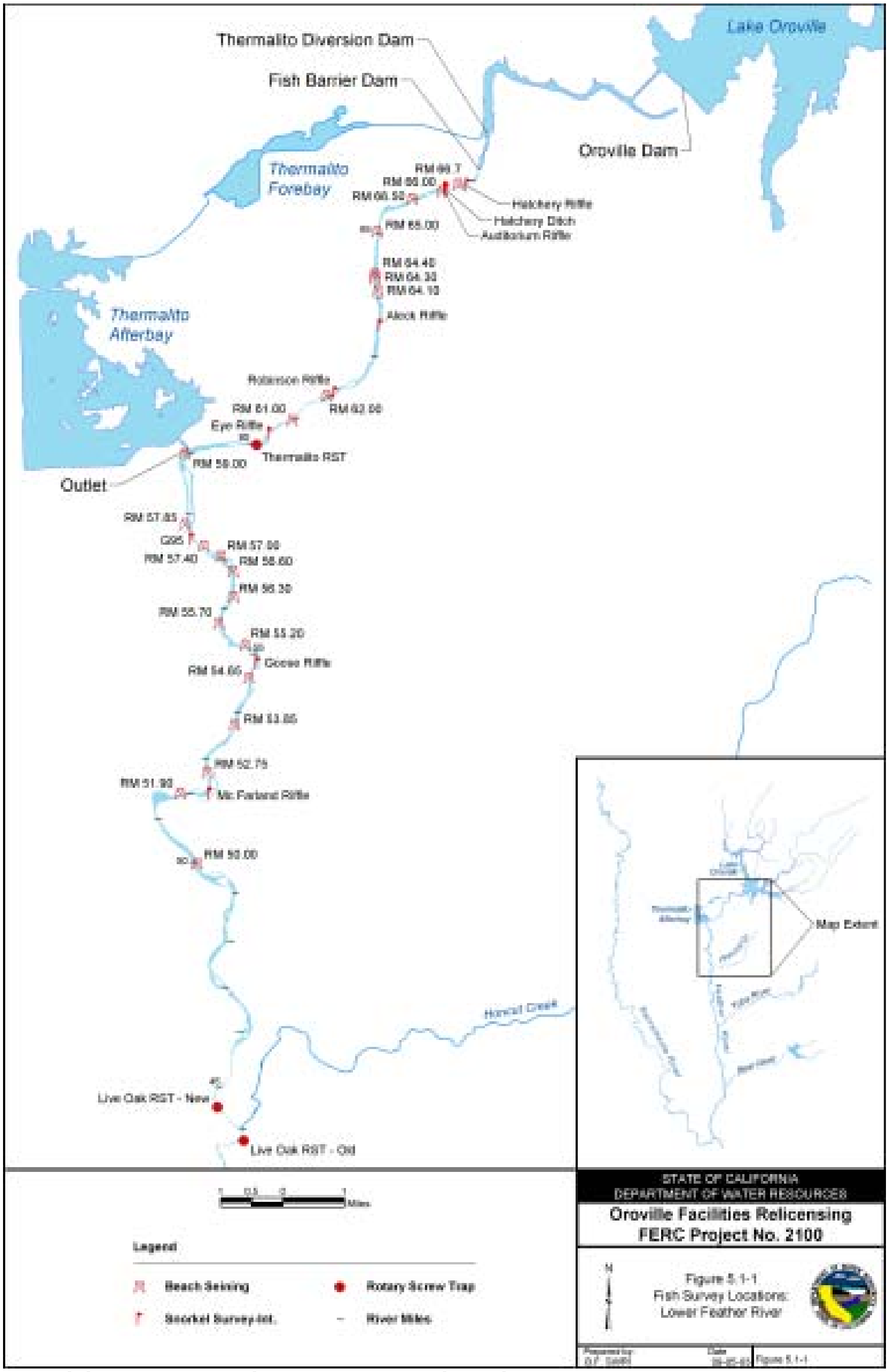

**Figure 5.1-1. Fish Survey Locations: Lower Feather River**

DWR conducted multi-scale snorkel surveys from 1999 through 2001 to provide information on the seasonal distribution, relative abundance, and habitat use of common Feather River fishes, particularly salmonids, and to identify river conditions, habitats, or ecological interactions which may limit the abundance of salmon and steelhead (Cavallo et al. 2003). The study area consisted of two segments. The Low Flow Channel (LFC) extended from the Fish Barrier Dam (RM 67.25) to the Thermalito Afterbay Outlet (RM 59). The High Flow Channel (HFC) extended from the Thermalito Afterbay Outlet to Gridley Bridge (RM 50.8) (Figure 5.1-1). Based on length frequency data, steelhead less than 100 mm FL were classified as age-0, while steelhead greater than 100 mm FL were designated as age-1+ (juvenile/adult). The observational data for all study years combined showed approximately 99% of age-0 steelhead and approximately 97% of age-1+ steelhead were observed in the LFC.

The combined results of these studies indicate: (1) the vast majority of juvenile steelhead, based on length at capture (Kelley 1988), were sampled shortly after emergence as fry; (2) juvenile steelhead were sampled in much greater numbers in the LFC than in the HFC; and (3) juvenile steelhead were present in the lower Feather River, to certain degrees, year-round (data is unavailable for September and October) in both the LFC and the HFC. DWR reports suggest that the catch in rotary screw traps indicates that many age-0 steelhead emigrate from the LFC shortly after emergence (Cavallo et al. 2003), and that steelhead emigration typically peaks in March and continues into April in most years (DWR 2002b). Because these post-emergent juvenile steelhead were not captured at the Live Oak RST, questions remain regarding the fate of post-emergent juvenile steelhead after they are captured in the Thermalito RST. It seems reasonable to suspect that if a large proportion of juvenile steelhead emigrated downstream of the LFC shortly after emergence as suggested (Cavallo et al. 2003), at a life stage most susceptible to capture, that more individuals would have been sampled at downstream sites, particularly during the RST study. One potential scenario is that between the Thermalito RST and the Live Oak RST, steelhead rear and grow to a size allowing them to avoid capture at the Live Oak RST. Additionally, the potential exists for post-emergent steelhead fry to migrate upstream to rear. Results from both the snorkel and seining studies support this hypothesis. Both of these studies reported juvenile steelhead of various sizes, suggesting multiple cohorts, present in the lower Feather River as late as August. However, the temporal distribution and relative numbers of each cohort was difficult to determine given the available data. The broad-scale snorkel survey results reported that a very high percentage of observations came from the LFC. Within the LFC, age-0 steelhead distribution was strongly skewed upstream, with 91%, 77%, and 84% of all observations occurring in the first river mile in each successive survey year, respectively (Cavallo et al. 2003). The intermediate-scale snorkel survey results were generally consistent with the broad-scale snorkel results (Cavallo et al. 2003). The broad-scale snorkel surveys were conducted from early May through mid-June and included the section of river from the Fish Barrier Dam (RM 67.25) to the Thermalito Afterbay Outlet (RM 59). Therefore, the overwhelming percentage of age-0 steelhead were observed between RM 67.25 and RM 66.25. The

Thermalito RST is located at RM 60.1. The large numbers of steelhead fry sampled from February through March at the Thermalito RST may simply reflect peak emergence dates, and not substantial downstream movements.

It is difficult to definitively determine the emigration time frame of juvenile steelhead in the lower Feather River based on a review of seining, rotary screw trap, and snorkeling data because of limited seasonal data, low numbers of fish sampled, a lack of steelhead fry captures from the Live Oak RST and a lack of larger individuals sampled. Juvenile steelhead have been reported to rear in natal streams and rivers for up to three years before emigrating out to sea (Boydstun 1977; McEwan and Jackson 1996; Moyle 2002). If this is the case, it is possible many emigrating juvenile steelhead are of a larger size, thus, the in-river migrational patterns of larger individuals may be more reflective of emigration timing. The lack of data for larger individuals makes it very difficult to define the emigration timing of juvenile steelhead. Size bias of sampling gear (Hayes et al. 1996) could explain the lack of larger individuals sampled during studies conducted in the lower Feather River. Juvenile steelhead were captured in the RST study primarily from mid-February through late April, with smaller numbers of fish being captured through June. The RST study concluded that, for juvenile steelhead, emigration typically peaks in March and continues into April in most years (DWR 2002b). BOR and DWR (2000) authored a biological assessment on the effects of the Central Valley Project and State Water Project on steelhead and spring-run Chinook salmon and concluded that juvenile steelhead in the Feather River emigrate from approximately mid-May through September (DWR 2000). This statement was based on a review of McEwan and Jackson 1996, DWR 1999a, 1999b, and 1999c, and unpublished data from DWR. It should be noted that a review of available literature, combined with results from studies conducted by DWR, revealed evidence suggesting juvenile steelhead in the lower Feather River rear year-round primarily in the LFC, and that emigration is a gradual process occurring during most months of the year. After careful review of available information and data, it seems most appropriate to combine results from the RST study, reports by BOR and DWR (2000), and what is known of the life history of juvenile steelhead in other river systems to use as a basis to delineate emigration timing of juvenile steelhead in the lower Feather River (DWR 2000). For purposes of this report, emigration of juvenile steelhead in the lower Feather River occurs primarily from February through September, with an apparent peak occurring from March through mid-April. It is uncertain if emigrating juvenile steelhead in the lower Feather River have begun the smoltification process. A brief analysis of water temperature from October through January is included, because available information and data suggests juvenile steelhead in the lower Feather River may emigrate during all months of the year.

### 5.1.2. Central Valley ESU Chinook Salmon

Several studies have documented emigration patterns of juvenile Chinook salmon in the lower Feather River. Painter et al. (1977) used fyke net catch data to determine the timing of juvenile Chinook salmon migrations in the Feather River, the relative numbers of juvenile Chinook salmon produced each year, and the effect of flows on production and migration patterns of juvenile Chinook salmon. Two to four fyke nets, deployed at Live Oak (RM 42) (Figure 5.1-1), were fished at least once per week from December 1968 through June 1973. Larger fyke nets were fished for twenty days at Live Oak from April 22 through June 13, 1975. All salmon captured were measured to the nearest mm FL. Juvenile salmon were captured in every month, with the vast majority of fish sampled from late January through March. Very few fish were sampled outside of the January through March period. The mean lengths of fry captured with the small nets ranged from 35 to 40 mm FL through March, and 75 to 85 mm FL in June. Most of the fish sampled with the larger nets were >60 mm FL. Painter et al. (1977) did not differentiate between juvenile spring-run Chinook salmon and juvenile fall-run Chinook salmon.

DWR conducted seining surveys in the lower Feather River between January 1997 and August 2001 to document fish distribution and abundance (DWR 2002a). Sampling sites were located between the Fish Barrier Dam (RM 67.25) and Boyd's Pump (RM 23) (Figure 5.1-1). The study area included two sections, the Low Flow Channel (LFC) from the Fish Barrier Dam to the Thermalito Afterbay Outlet (RM 59), and the portion of the High Flow Channel (HFC) from Thermalito Afterbay Outlet to Boyd's Pump. Total catch data were pooled for each section while length frequency distribution data were reported combining both sections. Only data for 1999, 2000, and 2001 were reported because these represented complete sampling seasons. Catch data were reported from December through August for each sampling season. Fork length (mm) was measured for the first 50 individuals captured. In 1999, 2000, and 2001 the percentage of juvenile Chinook salmon measuring ≤50 mm was approximately 74%, 66%, and 81%, respectively. When sample sizes for measured juvenile Chinook salmon were combined for all three sample years, approximately 73% of measured juvenile Chinook salmon were ≤50 mm. During the three years of this study, a total of 35,932 juvenile Chinook salmon were captured and 72 % of captures were within the HFC. Juvenile Chinook salmon were captured during all months of the study with January through March accounting for 73% of the catch. In all years, the highest numbers of juvenile Chinook salmon were sampled in February. When total catch numbers are combined for all three study years, the catch in February accounts for 43% of the total catch.

In addition to seining, DWR conducted multi-scale snorkel surveys from 1999 through 2001. Size categories were not recorded for juvenile Chinook salmon because nearly all were age-0 (Cavallo et al. 2003). As a result, this study did not differentiate between spring-run and fall-run juvenile Chinook salmon. Broad-scale surveys were conducted once per year. The 1999 survey was conducted from May 13 to May 26, the 2000 survey from June 5 to June 20, and the 2001 survey from May 1 to May 10. Large numbers of juvenile Chinook salmon were observed during these surveys in all years. Nearly all juvenile Chinook salmon observations (98%, 100%, and 99%, respectively) were within the LFC. Based on the methods section of the DWR 2003 report, survey effort appeared to be equal in both the LFC and the HFC. Intermediate-scale surveys were conducted monthly from March through August during each study year. In March and April, juvenile Chinook salmon were abundant and distributed somewhat evenly in both the LFC and the HFC. From May through August, juvenile Chinook salmon were seldom observed in the HFC. The number of juvenile Chinook salmon observations after April decreased substantially at all sites. It is uncertain why the number of observed juvenile Chinook salmon in May and June differed to the degree that it did between broad- and intermediate-scale surveys considering the apparent overlap of transects sampled, as described in the methods section of the DWR 2003 report.

DWR sampled juvenile salmonids in the lower Feather River from December 1998 through June 2001 using two RSTs in order to assess the timing and general abundance of emigrating juvenile Chinook salmon, steelhead and other fish species (DWR 2002b). The Thermalito RST was stationed at RM 60.1 and the Live Oak RST was stationed at RM 42 (Figure 5.1-1). Each trap was serviced at least once per day from mid-November through June. All Chinook salmon captured were counted and assigned to a race according to the criteria described by Greene (1992). Fork length was measured to the nearest mm for the first 50 individuals captured of each race. Measured individuals were also inspected for determination of life stage (i.e., parr, parr/smolt, and smolt). Spring-run sized juvenile Chinook salmon were captured primarily from late November through December, with numbers peaking in December. Most of these fish were <50 mm FL. A smaller pulse of spring-run sized fish occurred in April and May of 1999 and 2000. Fall-run sized Chinook salmon were captured primarily from mid-December through mid-April, with numbers peaking January through March. Most of these fish were <50 mm FL. In all years, small numbers of juvenile fall-run Chinook salmon were captured from late April through June. Results combining both races and all study years showed 97% of all juvenile Chinook salmon were captured prior to April 1. Combining catch data from all three study years, the period of January through March accounted for 91% and 97% of the total juvenile Chinook salmon catch at Live Oak and Thermalito, respectively. Chinook salmon measuring 35-38 mm FL dominated length distributions at both RSTs. Of the salmon trapped at Thermalito and Live Oak, 97% and 81% were less than 50 mm FL. The temporal length-frequency distribution showed little variation within and between RSTs. Also, temporal catch numbers were very similar between RSTs. The percentage of inspected juvenile Chinook salmon that were either smolt or parr/smolt was less than 2% at the Thermalito RST, and 15% at the Live Oak RST. Only 0.2% and 1.3% of the fish caught at Thermalito and Live Oak, respectively, were classified as true smolts.

The combined results of these studies indicate: (1) the majority of juvenile Chinook salmon, based on length at capture (Healey 1991), were sampled shortly after emergence as fry; (2) the greatest percentages of juvenile Chinook salmon were sampled from mid-November through March; (3) peak catches were made from January through March; (4) rearing juvenile Chinook salmon are present in the lower Feather River year-round, likely in very low numbers; and (5) almost all sampled juveniles had not begun the smoltification process (based on morphological characteristics) (DWR 2002b). Minimal variation in the temporal length-frequencies and catch/observation numbers within and between RSTs, and the similarity of results across studies, suggests juvenile Chinook salmon in the lower Feather River primarily emigrate shortly after emergence as fry. Emigration starts in mid-November and lasts primarily through March. Emigration persists, in small numbers, through June. The peak of emigration occurs from January through March. Most emigrants have not begun smoltification. These results are similar to those found in other Sacramento River tributaries (Snider et al. 1997; Yoshiyama et al. 1998). It is likely that a small percentage of young-of-year Chinook salmon remain in the river for extended periods to rear prior to downstream emigration.

Most data concerning the timing and characteristics of emigrating juvenile Chinook salmon in the lower Feather River have come from sample locations above (upstream) the Live Oak RST, with the exception of four seining sites, two slightly downstream of Live Oak and two in the vicinity of Yuba City (approximately RM 26). Little information is available regarding juvenile Chinook salmon emigration in the downstream-most 42 miles of the lower Feather River. Therefore, inferences can only be applied to the section of river upstream of Live Oak. The fate of emigrating juvenile Chinook salmon is unknown once they pass downstream of the Live Oak RST.

Several means are utilized to quickly determine the specific race, or run, of juvenile Chinook salmon sampled. The spawning period for each race is typically unique, with only slight overlap between races (Yoshiyama et al. 1998). Assuming universal time periods between incubation and initiation of emigration, the time period for which each race emigrates can be predicted. Another method involves using standardized daily fork-length tables (Greene 1992). Lengths of samples are compared, by sample date, to these standardized charts in order to determine race. Both methodologies are useful but should be used with caution due to inherent uncertainties. Environmental and physical variables can vary seasonally and yearly, which can influence the timing and duration of the spawning and emigration cycles. This, in turn, can cause more extensive overlap in emigration time frames between races. The RST study was the only study that attempted to differentiate between spring-run and fall-run juvenile Chinook salmon. Using daily fork-length tables (Greene 1992), DWR biologists concluded..."*most spring-run sized fish were nearly identical in size to the fall-run emigrating at the same time, clearly illustrating the uncertainties of using the Daily Length Table alone as an indicator of race* (DWR 2002b)".

For the purposes of this report, no distinction is made between spring-run juvenile Chinook salmon and fall-run juvenile Chinook salmon. The effects of water temperature on emigrating spring-run juvenile Chinook salmon and fall-run juvenile Chinook salmon are analyzed together over a range of months encompassing both spring-run Chinook salmon and fall-run Chinook salmon emigration periods, for several reasons. First, available data do not suggest different thermal requirements for juvenile spring-run and fall-run Chinook salmon. Rich (1997, section A-6-1) and Boles (1988) reviewed available literature and also found a lack of data distinguishing the thermal requirements of each race of Chinook salmon. Second, isolating emigration dates for each run would likely be difficult because overlap between spring-run juvenile Chinook salmon and fall-run juvenile Chinook salmon emigration dates has been found on the lower Feather River (DWR 2002b). Third, the collective results from studies described previously indicate that the emigration time frame for all races combined is contiguous. Therefore, analyzing the thermal effects during the collective emigration time period would be more efficient, effectively eliminating repeat analyses for certain months, although it is possible that temperature regimes affect emigrants from separate races differently.

## 5.2. ANALYTICAL TIME PERIODS FOR EMIGRATING JUVENILE STEELHEAD IN THE LOWER FEATHER RIVER

Delineation of emigration timing of juvenile steelhead in the lower Feather River was based on the results from this study, combined with reports by DWR and BOR (2000), and what is known of the life history of juvenile steelhead in other river systems. Juvenile steelhead in the lower Feather River emigrate from February through September, with peak emigration occurring from March through mid-April (DWR 2000; DWR 2002b). Analysis of water temperature and the potential effects of water temperature on emigrating juvenile steelhead therefore focuses on the time period of February through September. However, water temperatures from October through January also are evaluated because some information suggests that juvenile steelhead also may emigrate during this time period.

## 5.3. ANALYTICAL TIME PERIODS FOR EMIGRATING JUVENILE CHINOOK SALMON IN THE LOWER FEATHER RIVER

Emigration of juvenile Chinook salmon occurs from mid-November through June, with the largest numbers of emigrating Chinook salmon occurring from January through March. Analysis of water temperatures and the potential effects of water temperature on emigrating juvenile Chinook salmon focuses on the time period of November through June.

## 5.4. DEFINITION OF WATER TEMPERATURE INDICES FOR EMIGRATING JUVENILE STEELHEAD

Thermal effects on emigrating juvenile steelhead have been the focus of few studies. All reviewed published information has come from laboratory studies, usually utilizing hatchery-reared fish. The effects of elevated water temperatures have not been documented through field studies with wild fish in a natural setting. In general, only threshold temperatures were reported. Various ranges and degree of effect were not reported. Zaugg et al. (1972) demonstrated that the parr-smolt transformation may not occur or persist at a particular water temperature somewhere between 50$^{o}$ F (10$^{o}$ C) and 59$^{o}$ F (15$^{o}$ C). Adams et al. (1973) also reported this finding. Zaugg et al. (1972) suggest 53.6$^{o}$ F (12$^{o}$ C) as an upper limit for waters used by emigrating juvenile steelhead. In later years, Zaugg (1981) found that a water temperature of 53.6$^{o}$ F (12$^{o}$ C) could inhibit successful migration to the ocean in winter steelhead. Adams et al. (1975) reviewed the water temperature tolerances of hatchery summer strain steelhead from Washington State. Smoltification occurred in water temperatures at or below 52.3$^{o}$ F (11.3$^{o}$ C) but water temperatures above 50$^{o}$ F (10$^{o}$ C) may have contributed to desmoltification and decreased migratory behavior. Zaugg and Wagner (1973) conducted a similar study and had similar results. Winter steelhead showed a decrease in gill ATPase activity and decreased migratory behavior at water temperatures near 55.4$^{o}$ F (13$^{o}$ C). McEwan and Jackson (1996) stated that the optimum water temperatures for smoltification are below 57$^{o}$ F (13.9$^{o}$ C). A literature review, conducted by Wedemeyer et al. (1980), concluded that hatchery-spawned juvenile steelhead should be held below 55.4$^{o}$ F (13$^{o}$ C) for at least 60 days prior to release. Hoar (1988) also conducted a literature review and concluded the normal smolting increase in gill ATPase activity is suppressed or declines in steelhead at temperatures in excess of 55.4$^{o}$ F (13$^{o}$ C). Cech and Myrick (2000) determined that 62.6$^{o}$ F to 68$^{o}$ F (17$^{o}$ C to 20$^{o}$ C) was the preferred water temperature for both wild and hatchery Feather River juvenile steelhead. However, this laboratory study focused on preferred growth rate, and did not specifically focus on emigration.

The results from these studies should be applied to the lower Feather River with caution. These studies evaluated responses of individuals, not populations, to thermal gradients. Most stocks of laboratory fish were from regions where climatic conditions vary greatly from that of the Central Valley. Some speculate that Central Valley salmonid stocks are more resistant to higher water temperatures because they evolved in a more southerly climate with extreme temperatures, different than that of other salmonid runs (Cech and Myrick 2000). Bell (1991) reported that latitudinal differences in temperature tolerances for salmonids were approximately equal to one degree F for each degree change in latitude, with a positive north to south correlation. Therefore, the upper thermal tolerances of CV steelhead may be higher than those reported for most studies. Also, laboratory studies can isolate the effects of variables preventing interaction. This type of scenario does not occur in the field and the effects from thermal gradients are likely a complicated synergistic function of multiple variables. Thus, the summary and condensation of available data into a definitive set of thermal tolerance ranges for emigrating juvenile salmonids is problematic. With the exception of Cech and Myrick (2000), all studies reviewed reported adverse effects occurring between 50$^{o}$ F (10$^{o}$ C) and 59$^{o}$ F (15$^{o}$ C) but the average is near 55$^{o}$ F (12.8$^{o}$ C). The *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (2003) discusses criteria and describes an approach that EPA Region 10 encourages states and authorized tribes in the Pacific Northwest to use when adopting temperature water quality standards to protect coldwater salmonids (EPA 2003). These criteria were developed by a multi-agency panel through a review and summary of the latest literature related to temperature and salmonids. Based on the criteria in this publication (pages 19 and 25), the EPA suggests that water temperatures should not exceed 54.5$^o$ F (12.5$^o$ C) when steelhead are emigrating.

A review of literature pertaining to the thermal effects on fish found a wide variety of categorical definitions for thermal tolerance ranges. To avoid confusion or misinterpretation, the terms for each index category used in the report contained herein are defined. These definitions closely parallel those outlined in McCullough (1999), and were chosen in order to remain consistent with language found in other reports associated with SP-F10. Four categories were chosen to describe water temperature index ranges that have different effects upon fish. "Suitable" water temperature index ranges provide for normal feeding, behavioral, and physiological responses. "Not suitable" water temperature index ranges inhibit feeding, behavioral, and physiological responses. "Potential sub-lethal" water temperatures have been reported to contribute to thermal stress loading and have immediate or delayed adverse affects, including mortality, upon fish. The "upper incipient lethal effects" (UILT) are water temperature index ranges that reportedly cause approximately 50% mortality. Mortalities are expected if water temperatures reach the upper incipient lethal index range, although the extent of mortalities, and whether direct or delayed, are unknown. Adverse affects from cold water will not be analyzed in this report, because the Feather River is located at the southern extent of the geographic range for salmonids, and river water temperatures do not get cold enough to exert cold-water thermal stress.

For this evaluation of water temperature effects on emigrant steelhead in the lower Feather River, water temperatures less than or equal to 55$^o$ F (12.8$^o$ C) are considered as an index of suitable water temperature. The index value of 65$^o$ F (18.3$^o$ C) is also useful to evaluate project effects because this value is used as an explicit criterion by NOAA Fisheries for the lower Feather River (NOAA 2002). In a biological opinion issued in September 2002, NOAA Fisheries concluded that "...*for fry and juvenile steelhead and spring-run Chinook salmon, water temperatures between 45$^o$ F and 65$^o$ F are preferred for growth and development*". The biological opinion mandates DWR, under section D "Terms and Conditions", to control water temperatures at RM 61.6 (Robinson Riffle), by flow releases, from June 1 through September 30 to a daily average temperature of less than or equal to 65$^o$ F to protect over-summering steelhead from thermal stress, and from warm water predator species. To remain consistent with established conventions, for purposes of this report, water temperatures greater than 65$^o$F are defined as "not suitable" for emigrating steelhead. Water temperatures greater than 55$^o$ F and less than or equal to 65$^o$ F are defined as those incurring potential sub-lethal effects on emigrating steelhead.

## 5.5. DEFINITION OF WATER TEMPERATURE INDICES FOR EMIGRATING JUVENILE CHINOOK SALMON

Most studies evaluating thermal ranges preferred or avoided by juvenile Chinook salmon have been laboratory studies using hatchery-reared fish. Data specific to the thermal profiles preferred by emigrating juvenile Chinook salmon in the lower Feather River are unavailable. Two types of studies have generally been conducted to evaluate thermal effects on juvenile Chinook salmon. Many studies focused on thermal stress and resulting mortalities. In general, fish were acclimated at different water temperatures, and then exposed to various higher water temperatures until mortalities occurred. Other studies had similar methodologies, but included behavioral, physiological, and morphological measurements. The results from this second type of study are of particular interest because the smoltification process (physiological and behavioral changes) is an integral component of emigration. It is difficult to compare results across studies because acclimation temperatures and diets differed, and other stress factors were not controlled for. Because stress factors work synergistically, the amount of adverse effect attributable to water temperature is difficult to assess both within and among studies. Also, wild fish exist in a more temporally and spatially heterogeneous thermal environment. Therefore, the results from laboratory studies using hatchery-spawned stocks should be applied to wild stocks with caution.

Brett (1952) used hatchery strain juvenile Chinook salmon from Washington and British Columbia to determine various water temperature tolerance ranges. By varying acclimation water temperatures and exposure times, he determined the upper incipient lethal water temperature was somewhere between 75.2$^{o}$ F (24$^{o}$ C) and 76.1$^{o}$ F (24.5$^{o}$ C). He also reported a suitable (described as preferred in the study) range of 53.6$^{o}$ F to 55.4$^{o}$ F (12$^{o}$ C to 13$^{o}$ C) and a lower incipient lethal water temperature of 45.3$^{o}$ F (7.4$^{o}$ C). Orsi (1971) conducted a laboratory study with hatchery strain fish from the Nimbus Hatchery on the American River and the Feather River Hatchery. Mortality was measured as a function of thermal stress. The study documented that juvenile salmonids could endure higher water temperatures when acclimation water temperatures were higher, although lethal water temperatures rose more slowly than acclimation water temperature. An upper incipient lethal water temperature of approximately 78$^{o}$ F (25.6$^{o}$ C) was reported. The reported water temperature is higher than those found in many studies but remains consistent with other studies that utilized salmon strains from the Sacramento River system. Rich (1987) explored growth rates and survival rates by using hatchery-reared juvenile Chinook salmon from the American River. Fish received maximum food rations at various water temperatures. The reported optimal water temperature range was 54$^{o}$ F to 59.9$^{o}$ F (12.2$^{o}$ C to 15.5$^{o}$ C). Baker et al. (1995) modeled 7 years of trawl data from the Sacramento-San Joaquin Delta and reported an upper incipient lethal water temperature of 73.4$^{o}$ F $\pm$ 1.8$^{o}$ F (23$^{o}$ C $\pm$ 1$^{o}$ C). Marine (1997) stated that, although they did not establish a specific upper incipient lethal water temperature for the Sacramento River Chinook salmon used for the experiments, the data appeared to indicate a similar sub-lethal growth stress threshold for this stock at about 68$^{o}$ F to 69.8$^{o}$ F (20$^{o}$ C to 21$^{o}$ C). He also reported that his data indicated that both acceleration and inhibition of Sacramento River Chinook salmon smolt development may occur at water temperatures above 62.6$^{o}$ F (17$^{o}$ C), and significant inhibition of gill ATPase activity and associated reductions of hypo-osmoregulatory capacity may occur when chronic elevated temperatures exceed 68$^{o}$ F

(20$^{o}$ C). Healey (1977) exposed eggs and fry of Sacramento River strain fish to various water temperatures and reported that survival to the fingerling stage was 20% or less when developing fry were exposed to 60$^{o}$ F to 61$^{o}$ F (15.5$^{o}$ C to 16.1$^{o}$ C) water temperatures for prolonged periods. Most juvenile Chinook salmon in the lower Feather River begin emigration as fry, thus, the results from this study may be particularly relevant. Several studies explored growth rates of juvenile Chinook salmon in relation to water temperature. Brett (1982) found highest growth rates at about 66.2$^{o}$ F (19$^{o}$ C) while Banks et al. (1971) reported 60$^{o}$ F to 65$^{o}$F (15.6$^{o}$ C to 18.3$^{o}$ C) as the optimum water temperature range for growth. Several authors conducted literature reviews to delineate thermal ranges for juvenile Chinook salmon. Boles (1988) stated that although specific water temperature limits have not been determined for Chinook salmon, a maximum water temperature of 54$^{o}$ F (12.2$^{o}$ C) for all species of salmonids has been recommended to maintain migratory response and seawater adaptation in juveniles, although source data were not available. Citing Rich (1997), DFG (1998) stated that the optimal thermal range for smoltification and seaward migration is 50$^{o}$ F to 55$^{o}$F (10$^{o}$ C to 12.8$^{o}$ C).

It is important to note that effects from water temperature are life stage-, species-, and site-specific. Also, different water temperatures can affect the physiological and behavioral aspects of emigrating salmonids in different ways (Marine 1997). For example, a certain water temperature may promote excellent growth rates but provide poor conditions for the smoltification cycle. Both are important to survivability, yet suitable water temperatures for each are different, which compounds the difficulty of defining thermal tolerance ranges. A summary of studies with the objective of evaluating growth rates and water temperature suggests a reported low optimal water temperature of 54$^{o}$ F (12.2$^{o}$ C) and a reported high optimal water temperature of 66.2$^{o}$ F (19$^{o}$ C). However, most authors reported that optimal growth rates occurred when water temperatures were near 65$^{o}$ F (18.3$^{o}$ C). A summary of those studies that simply assessed mortality as a function of water temperature and exposure times exhibited much more variation in reported ranges. Suitable water temperatures ranged from 53.6$^{o}$ F to 59$^{o}$ F (12$^{o}$ C to 15$^{o}$ C), upper incipient lethal water temperature ranged from 68$^{o}$ F to 78$^{o}$ F (20$^{o}$ C to 25.6$^{o}$ C), and Brett (1952) reported a lower incipient lethal water temperature of 45.3$^{o}$ F (7.4$^{o}$ C). Marine (1997) examined physiological response associated with smoltification to water temperature. He reported that inhibition of the gill ATPase activity began at temperatures above 62.6$^{o}$ F (17$^{o}$ C) and chronic inhibition occurred above 68$^{o}$ F (20$^{o}$ C). Interpretation of the results from Marine (1997) suggests that suitable water temperatures are $\leq$62.6$^{o}$ F (17$^{o}$ C), potential sub-lethal effects occur at water temperatures between 62.6$^{o}$ F and 68$^{o}$ F (17$^{o}$ C and 20$^{o}$ C), and the upper incipient lethal water temperature is 68$^{o}$ F (20$^{o}$ C). Considerable weight will be given to the results from Marine (1997) because he evaluated a physiological component of smoltification, and smoltification is an integral part of emigration.

Based on a review of available literature, the report contained herein concludes that, for emigrating juvenile Chinook salmon, several indices are useful to evaluate project operations. The indices are defined as less than or equal to 62.6° F (17° C) at which water temperatures are considered suitable, water temperatures greater than 62.6° F and less than or equal to 68° F (20° C) are considered to induce potential sub-lethal effects, and water temperatures greater than 68° F are considered to be the upper incipient lethal range. "Suitable" water temperature ranges provide for normal feeding, behavioral, and physiological responses. "Potential sub-lethal effects" are those water temperature ranges that have been reported to contribute to thermal stress loading and have immediate or delayed adverse affects, including mortality, upon fish. The "upper incipient lethal effects" (UILT) are water temperature ranges that reportedly cause approximately 50% mortality. Mortalities are expected if water temperatures reach the upper incipient lethal effects range, although the extent of mortalities, and whether direct or delayed, are unknown. As mentioned in section 5.5, the additional index of 65° F (18.3° C) is also useful as an index for evaluating project effects because this value is used as an explicit criterion by NOAA Fisheries for the lower Feather River (NOAA 2002).

## 5.6. WATER TEMPERATURE IN THE LOW FLOW CHANNEL OF THE LOWER FEATHER RIVER AND ASSOCIATED EFFECTS TO EMIGRATING JUVENILE SALMONIDS

### 5.6.1 Central Valley ESU Steelhead

During the time period that water temperature data were collected, the temporal suitability of the water temperature regimes in the LFC, with regard to emigrating juvenile steelhead, were variable (Appendix A). Maximum daily water temperatures represent the most potentially stressful water temperature to which emigrating juvenile steelhead in the lower Feather River would be exposed. Relative to the thermal tolerance index of 55° F (12.8° C), during the defined emigration period of February through September, maximum daily water temperatures generally remained within the defined suitable index range (≤55° F), in the upper section of the LFC (RM 67.4 to RM 66.0), from February through May, and from late August through September (for example, **Figure 5.6-1**). For the remainder of the LFC (RM 64.1 to RM 59.4), maximum daily water temperatures, during the defined emigration period, generally remained within the defined suitable index range from February through late March (Appendix A). Mean and minimum daily water temperatures in the upper section of the LFC (RM 67.4 to RM 66.0) generally remained within the defined suitable index range from February through May (sometimes into June), and late August through early September. For the remainder of the LFC (RM 64.1 to 59.4), mean and minimum daily water temperatures, during the defined emigration period, remained within the defined suitable index range during February and March.

Relative to the thermal tolerance index of 65° F (18.3° C), maximum daily water temperatures, from RM 67.4 to RM 64.1, generally remained below 65° F year-round. For the remainder of the LFC (RM 61.7 to 59.4), maximum daily water temperatures, during the defined emigration period, generally remained below 65° F in September, and February through mid-June. Mean and minimum daily water temperatures throughout the LFC (RM 67.4 to RM 59.4), generally remained below 65° F year-round. At Robinson Riffle (RM 61.7), mean daily water temperatures, for the time period during which temperature data were available, exceeded 65° F only once on June 19, 2002.

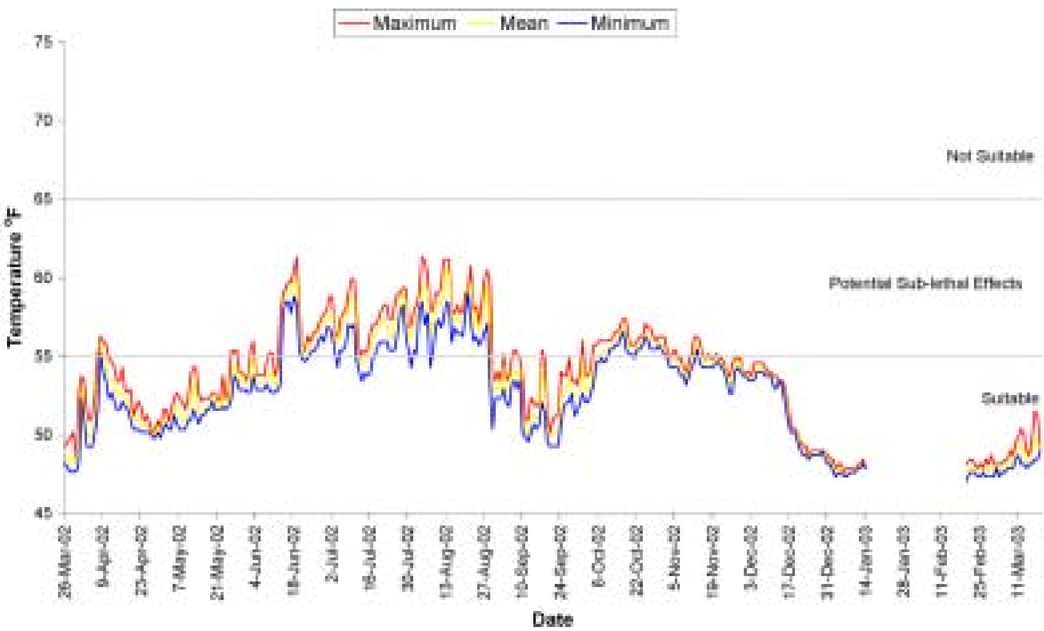


**Figure 5.6-1. Steelhead Thermal Ranges and Water Temperature Profile Downstream from Diversion Dam - River Mile 67.4**

In the spawning channel (RM 66.2), maximum daily water temperatures, during the defined emigration period, generally remained within the defined suitable index range ($\leq$55° F, 12.8° C) briefly in April (**Figure 5.6-2**). Mean and minimum daily water temperatures in the spawning channel generally remained within the defined suitable index range in September, and February through May. Relative to the thermal tolerance index of 65° F (18.3° C), maximum daily water temperatures in the spawning channel exceeded 65° F on various occasions during the months of June, July, and August. Mean and minimum daily water temperatures in the spawning channel remained below 65° F year-round.

Juvenile steelhead potentially emigrate year-round, so a brief summary of water temperatures in the LFC from October through January is provided. Throughout the LFC (RM 67.4 to RM 59.4), maximum, mean, and minimum daily water temperatures, outside of the defined emigration period, generally remained within the defined suitable index range ($\leq$55° F, 12.8° C) from mid-November through January. Throughout the LFC (RM 67.4 to RM 59.4), maximum, mean, and minimum daily water temperatures remained below 65° F (18.3° C) year-round.

Maximum daily water temperatures in the LFC of the lower Feather River, during the defined emigration period for juvenile steelhead, may be cause for concern. However, maximum daily water temperature is a single data point, and does not persist throughout a diel cycle. Because the effects from thermal stress have been reported to be positively correlated with exposure times, mean daily water temperature may be a more appropriate variable with which to gauge potential effects from thermal stress. Mean daily water temperatures throughout the LFC (RM 67.4 to RM 59.4) remained within the defined suitable index range ($\leq 55^{o}$ F, $12.8^{o}$ C) during the extent of the reported peak of juvenile steelhead emigration on the lower Feather River (March through mid-April). Conclusions reported do not apply to those sections of river or for those blocks of dates when water temperature data were unavailable.

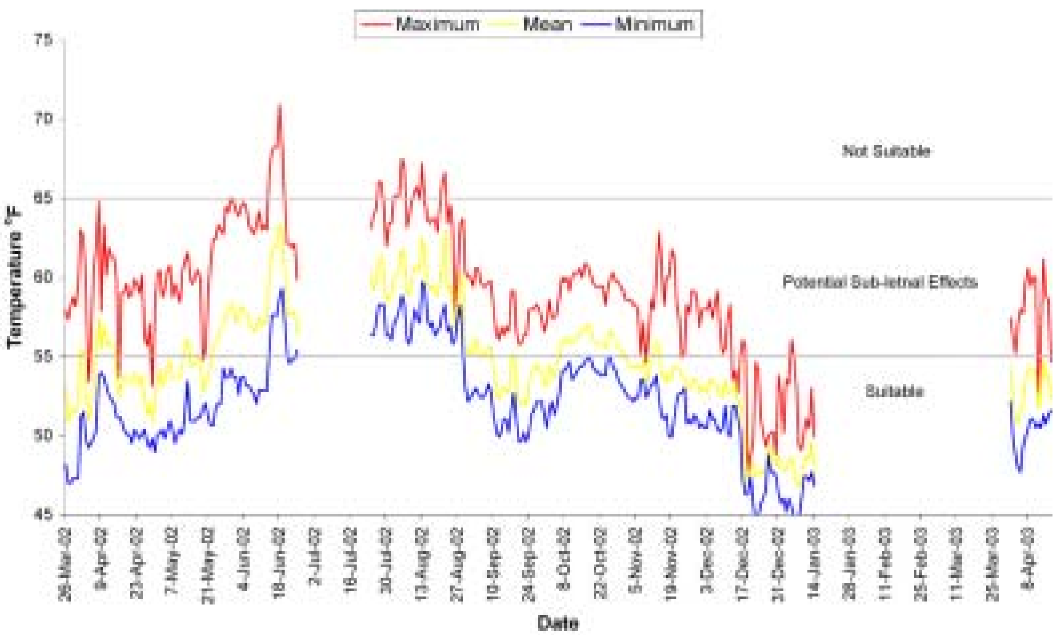


**Figure 5.6-2. Steelhead Thermal Ranges and Water Temperature Profile at the Spawning Channel - River Mile 66.2**

## 5.6.2 Central Valley ESU Chinook Salmon

Water temperature profiles for each water temperature logging station in the LFC and the associated thermal tolerance index ranges for emigrating juvenile Chinook salmon are shown in Appendix A. Relative to the thermal tolerance suitability index of $62.6^{o}$ F ($17^{o}$ C), during the time period that water temperature data were collected, daily maximum, mean, and minimum water temperatures remained within the defined suitable index range ($\leq 62.6^{o}$ F) year-round, from RM 67.4 downstream to RM 64.1 (for example, **Figure 5.6-3**). Maximum daily water temperatures, during the defined emigration period, remained within the defined suitable index range, from RM 61.7 to

RM 59.4, from mid-November through late May (for example, **Figure 5.6-4)**. Mean and minimum daily water temperatures remained within the defined suitable index range, from RM 61.7 to RM 59.4, from mid-November through mid-June.

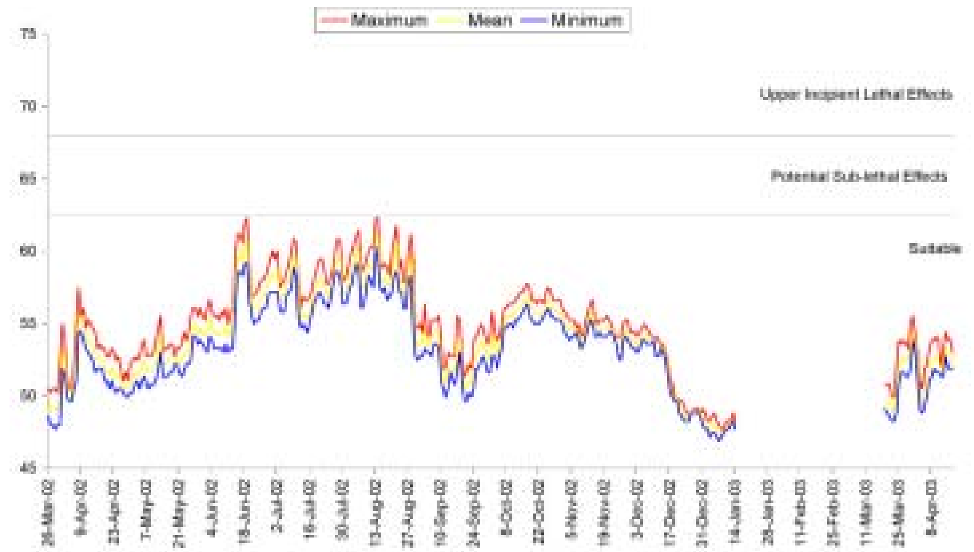


**Figure 5.6-3. Chinook Salmon Thermal Ranges and Water Temperature Profile at Auditorium Riffle - River Mile 66.2**

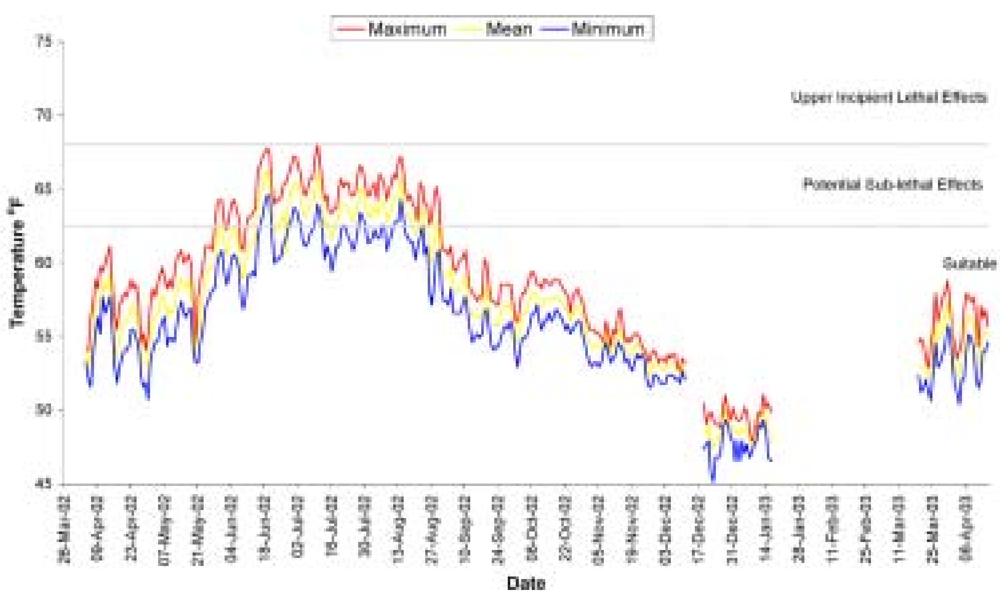


**Figure 5.6-4. Chinook Salmon Thermal Ranges and Water Temperature Profile Upstream from Afterbay Outlet - River Mile 59.4**

Relative to the thermal tolerance suitability index of 68° F (20° C), maximum daily water temperatures throughout the extent of the LFC (RM 67.4 to RM 59.4) very rarely exceeded 68° F (four days at RM 60.2 and one day at RM 59.4). Mean and minimum daily water temperatures, throughout the extent of the LFC, did not exceed 68° F.

In the spawning channel (RM 66.2), maximum daily water temperatures, during the defined emigration period, generally remained within the defined suitable index range (≤ 62.6° F, 17° C) from mid-November through late May. Mean and minimum daily water temperatures in the spawning channel generally remained within the defined suitable index range during the extent of the defined emigration period (mid-November through June). Relative to the thermal tolerance index of 68° F (20° C), maximum daily water temperatures in the spawning channel exceeded 68° F on few occasions in mid-June. Mean and minimum daily water temperatures in the spawning channel remained below 68° F year-round. The highest water temperature recorded in the LFC was 70.9° F (21.6° C) on June 18, 2002 in the spawning channel.

In general, it is likely the thermal profile of the LFC in the lower Feather River provides an environment conducive for normal emigration processes, both physiologically and behaviorally. As previously stated, it has been reported that juvenile Chinook salmon in the lower Feather River emigrate from mid-November through June, with the peak of emigration occurring from January through March. Water temperatures from RM 61.7 to the most downstream temperature data logger in the LFC (RM 59.4) may be cause for slight concern. In this stretch of the river, daily water temperatures, during the defined emigration period, consistently exceeded the suitable index range during June. However, the daily maximum, mean, and minimum water temperatures, during the time period for which water temperature data were available, never exceeded the suitable index range during the reported peak emigration period for juvenile Chinook salmon (January through March). Annual water temperatures within the LFC of the lower Feather River appear to be generally suitable for emigrating juvenile Chinook salmon. Conclusions reported do not apply to those sections of river or for those blocks of dates when water temperature data were unavailable.

## 5.7 WATER TEMPERATURE IN THE HIGH FLOW CHANNEL OF THE LOWER FEATHER RIVER AND ASSOCIATED EFFECTS TO EMIGRATING JUVENILE SALMONIDS

### 5.7.1 Central Valley ESU Steelhead

Water temperature profiles for each water temperature logging station in the HFC and the associated thermal tolerance index ranges for emigrating juvenile steelhead are shown in Appendix A. Relative to the thermal tolerance index of 55° F (12.8° C), during the defined emigration period of February through September, maximum, mean, and minimum daily water temperatures generally remained within the defined suitable index range (≤55° F), throughout the extent of the HFC (RM 58.8 to RM 0.3), from February through early March (for example, **Figure 5.7-1**). Although water temperature data gaps occurred for many of the water temperature loggers during the coldest periods of the year, thermal profiles of loggers with unavailable data were assumed to be the same as adjacent downstream loggers with available data.

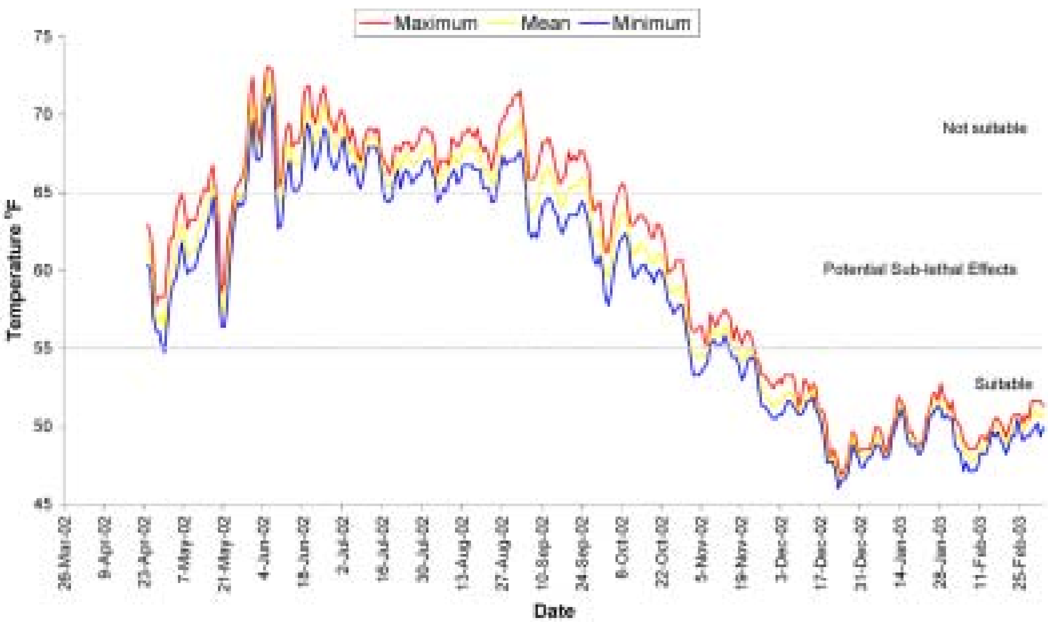


**Figure 5.7-1. Steelhead Thermal Ranges and Water Temperature Profile at Star Bend - River Mile 18.2**

The thermal regime at the mouth of the Yuba River (RM 27.5) deviated from the other water temperature logging locations. The mean and minimum daily water temperatures at the mouth of the Yuba River (RM 27.5) remained at or below 55$^{o}$ F up to two months longer in the spring (April, May) than at any of the other water temperature logging locations in the HFC (**Figure 5.7-2**).

Relative to the thermal tolerance index of 65$^{o}$ F (18.3$^{o}$ C) from RM 58.8 to RM 58.6, during the defined emigration period, maximum daily water temperatures generally remained below 65$^{o}$ F from February through May. Maximum daily water temperatures, from RM 57.3 to RM 28.2, generally remained below 65$^{o}$ F from February through March and late August through September, and sporadically from April through May. Maximum daily water temperatures at the mouth of the Yuba River (RM 27.5) generally remained below 65$^{o}$ F from February through May. Maximum daily water temperatures in the remainder of the HFC (RM 25.2 to RM 0.3) generally remained below 65$^{o}$ F from February through late May. Mean and minimum daily water temperatures from RM 58.8 to RM 41.8,during the defined emigration period, generally remained below 65$^{o}$ F from February through May and September, and sporadically from June through July. Mean and minimum daily water temperatures at the mouth of the Yuba River (RM 27.5), during the defined emigration period, generally remained below 65° F from February through August. Mean and minimum daily water temperatures for the remainder of the HFC (RM 25.2 to RM 0.3) remained below 65° F from February through mid-May.

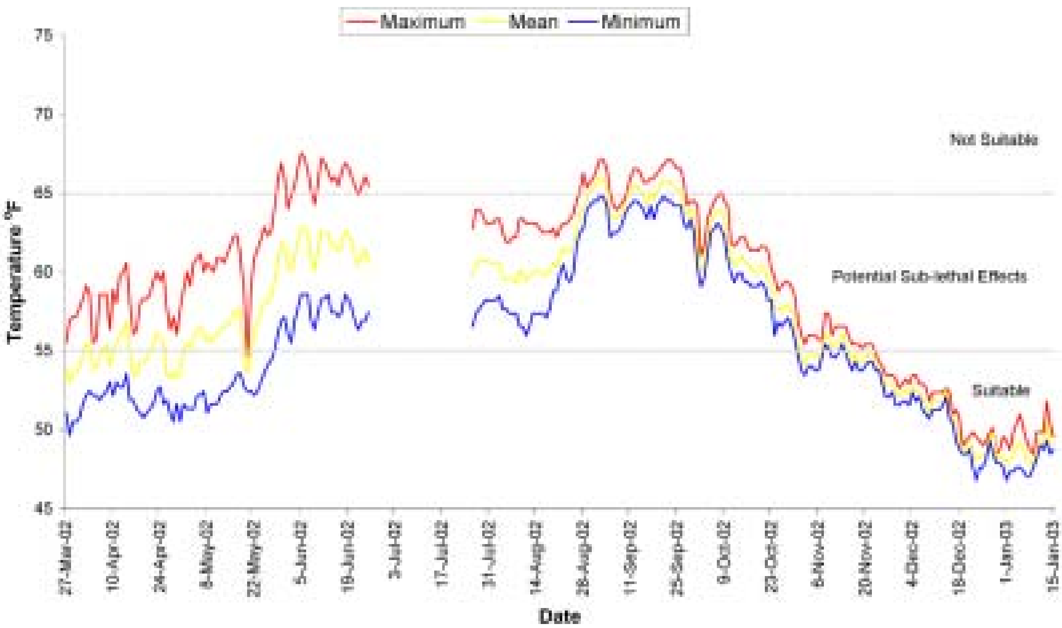


**Figure 5.7-2. Steelhead Thermal Ranges and Water Temperature Profile at Mouth of Yuba River - River Mile 27.5**

Juvenile steelhead potentially emigrate year-round, so a brief summary of water temperatures in the HFC from October through January is provided. Maximum daily water temperatures throughout the HFC (RM 58.8 to RM 0.3), outside of the defined emigration period, generally remained within the defined suitable index range (≤55° F, 12.8° C) from late November through January. Mean and minimum daily water temperatures throughout the HFC (RM 58.8 to RM 0.3), outside of the defined emigration period, generally remained within the defined suitable index range from mid-November through January. Maximum, mean, and minimum daily water temperatures, throughout the HFC (RM 58.8 to RM 0.3), generally remained below 65° F (18.3° C) from October through January.

## 5.7.2 Central Valley ESU Chinook Salmon

Water temperature profiles for each water temperature logging station in the HFC and the associated thermal tolerance index ranges for emigrating juvenile Chinook salmon are shown in Appendix A. Relative to the thermal tolerance index of 62.6° F (17° C) from RM 58.8 to RM 58.6, during the defined emigration period, maximum daily water temperatures generally remained within the defined suitable index range (≤ 62.6° F) from mid-November through mid-May (for example, **Figure 5.7-3**). Maximum daily water temperatures for the remaining logging stations (RM 57.3 to RM 0.3), during the defined emigration period, generally remained within the defined suitable index range from mid-November through early April. Maximum daily water temperatures at the mouth of the Yuba River (RM 27.5) generally remained within the defined suitable index range from mid-November through May. Mean and minimum daily water temperatures from RM 58.8 to RM 58.6 generally remained within the defined suitable index range from mid-November through May. Mean and minimum daily water temperatures from RM 57.3 to RM 28.2 generally remained within the defined suitable index range from mid-November through early April. Mean and minimum daily water temperatures at the mouth of the Yuba River (RM 27.5), during the defined emigration period, generally remained within the defined suitable index range from mid-November through June. For the remainder of the HFC (RM 25.2 to RM 0.3), mean and minimum daily water temperatures generally remained within the suitable index range from mid-November through late April.

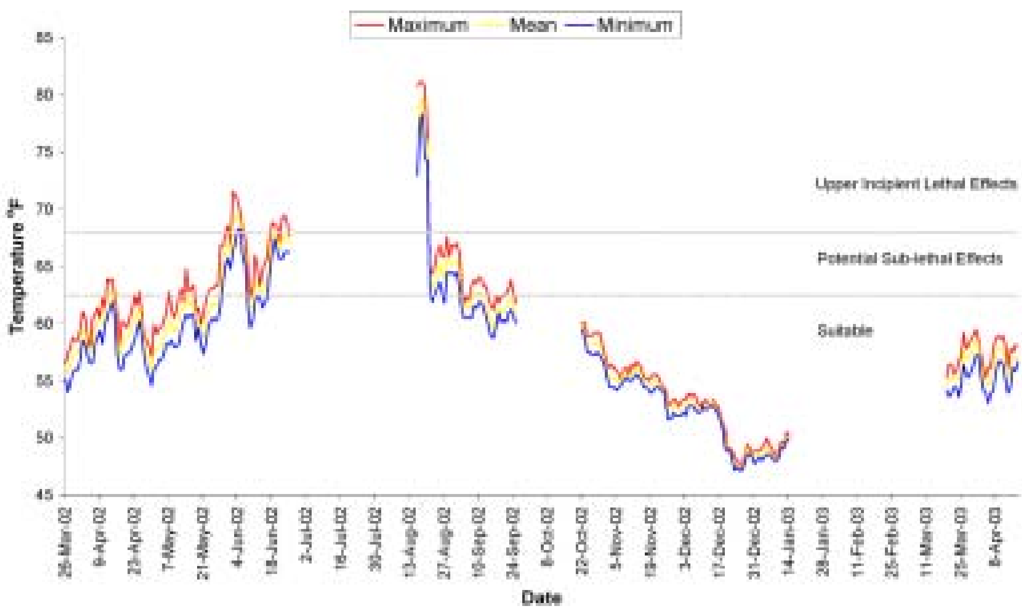


**Figure 5.7-3. Chinook Salmon Thermal Ranges and Water Temperature Profile Downstream from Afterbay Outlet - River Mile 58.6**

Relative to the thermal tolerance index of 68$^o$ F (20$^o$ C), maximum daily water temperatures throughout the extent of the HFC (RM 58.8 to RM 0.3), during the defined emigration period, generally remained below 68$^o$ F from mid-November through late May (for example, **Figure 5.7-4**). Maximum daily water temperatures at the mouth of the Yuba River (RM 27.5) remained below 68$^o$ F year-round. Mean and minimum daily water temperatures from RM 58.8 to RM 57.3 generally remained below 68$^o$ F from mid-November through June. For the remainder of the HFC (RM 53.5 to RM 0.3), mean and minimum daily water temperatures generally remained below 68$^o$ F from mid-November through late May. Mean and minimum daily water temperatures at the mouth of the

Yuba River (RM27.5) remained below 68° F year-round. The highest recorded water temperature in the HFC was 77.7° F (25.4° C) from RM 28.2 on May 31, 2002, and from RM 9.3 on June 5, 2002.

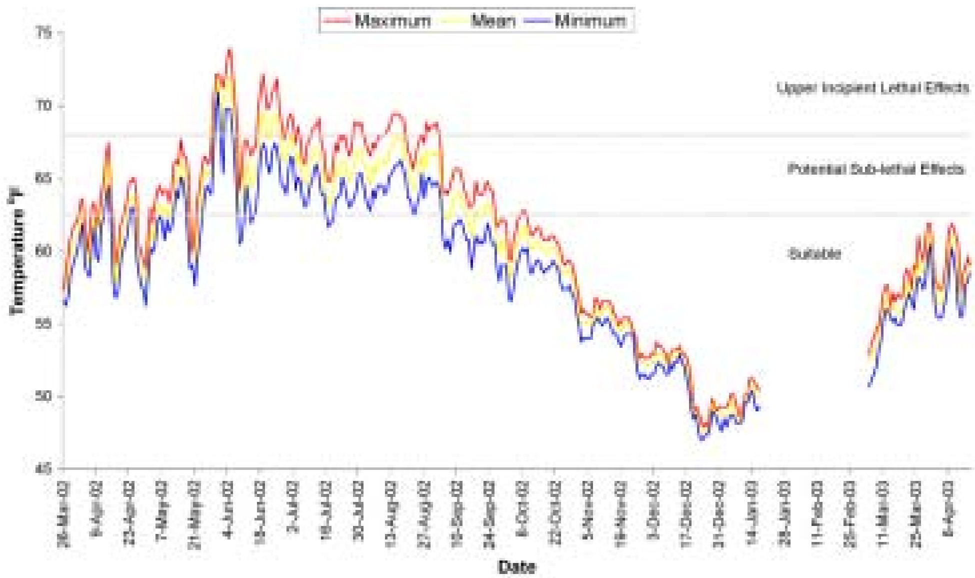


**Figure 5.7-4. Chinook Salmon Thermal Ranges and Water Temperature Profile at Singh above Riviera Road - River Mile 45.9**

Mean daily water temperatures in the HFC of the lower Feather River exceeded the suitable water temperature index range (62.6° F) primarily from late May through June. During the peak of emigration, from January through March, daily maximum, mean, and minimum water temperatures did not exceed 62.6° F. Emigrating juvenile Chinook salmon in the HFC of the lower Feather River potentially experience thermal stress from late May through June. However, RST data indicate that the vast majority (approximately 96%) of emigrant juvenile Chinook salmon have left the lower Feather River prior to late May. The extent of the thermal stress, and its ultimate effects, are unknown. Of note was the water temperature profile for the water temperature logging station located at the mouth of the Yuba River RM 27.5. Water temperatures recorded at this station from approximately January 1 through mid-August were consistently lower than water temperatures recorded at adjacent stations (**Figure 5.7-5**). During the warmest months of the year, cold-water inflow from the Yuba River may provide thermal refugia for emigrating juvenile Chinook.

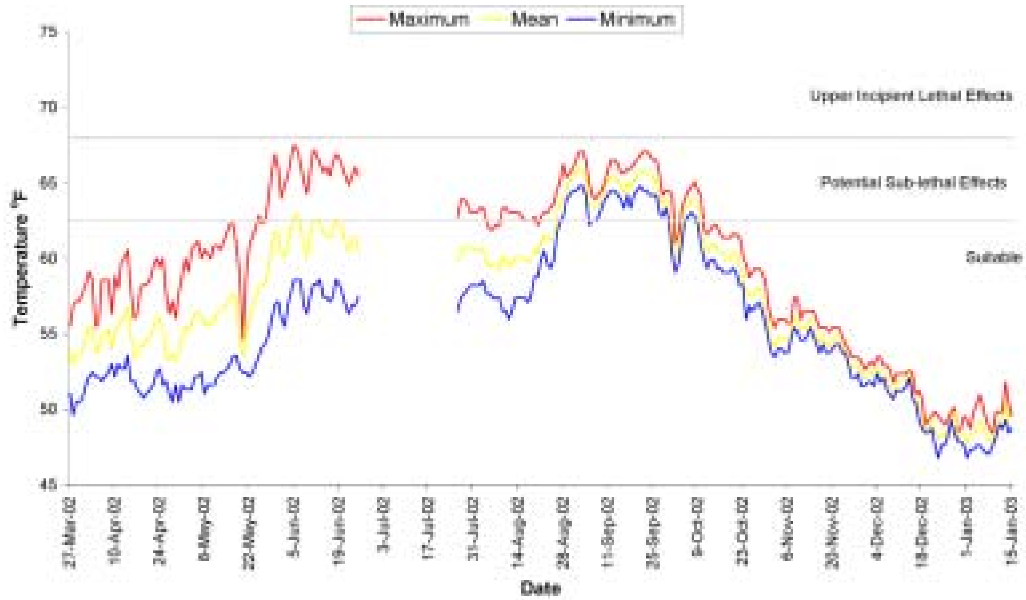


**Figure 5.7-5. Chinook Salmon Thermal Ranges and Water Temperature Profile at Mouth of Yuba River - River Mile 27.5**

# 6.0 CONCLUSIONS

Elevated water temperatures in the lower Feather River may affect emigrating juvenile steelhead to a greater degree than emigrating juvenile Chinook salmon. Water temperatures in the LFC are more conducive to emigrating salmonids than are the water temperatures in the HFC. Juvenile steelhead have been reported to emigrate from February through September, with peak emigration occurring from March through mid-April. Water temperatures in the LFC generally exceeded the defined suitability index ($\leq$55° F, 12.8° C) for emigrating juvenile steelhead from May through September. Mean daily water temperatures from February through April (which accounts for the extent of peak emigration), for 100% of the linear extent of the LFC, generally remained within the defined suitable index range for emigrating juvenile steelhead. Mean daily water temperatures during May and mid-August through September, for 23% of the linear extent of the LFC, generally were within the suitable index range for emigrating juvenile steelhead. Water temperatures in the HFC exceeded the defined suitable index range for emigrating juvenile steelhead primarily from mid-March through September. Mean daily water temperatures from February through early March, for 100% of the linear extent of the HFC, generally remained within the defined suitable index range for emigrating juvenile steelhead. In the LFC, mean daily water temperatures rarely exceeded the index value of 65° F (18.3° C). In the HFC, mean daily water temperatures generally exceeded 65° F from mid-April through September. Approximately 95% of juvenile steelhead emigrate in the lower Feather River from March through mid-April (DWR 2002b). During this time period, mean daily water temperatures throughout much of the lower Feather River within the project boundary were within the suitable index range.

Juvenile Chinook salmon have been reported to emigrate from mid-November through June, with peak emigration occurring from January through March. In the LFC, water temperatures generally exceeded the defined suitable index range ($\leq$62.6° F, 17° C) for emigrating juvenile Chinook salmon during June. However, the vast majority (approximately 96%) of emigrant juvenile Chinook salmon have left the lower Feather River prior to late May. Mean daily water temperatures from mid-November through early June, for 100% of the linear extent of the LFC, were generally suitable for emigrating juvenile Chinook salmon. In the HFC, water temperatures generally exceeded the defined suitable index range for emigrating juvenile Chinook salmon from late May through June. Mean daily water temperatures from mid-November through mid-May, for 100% of the linear extent of the HFC, were generally suitable for emigrating juvenile Chinook salmon.

# 7.0 REFERENCES

Adams, B. L., W. S. Zaugg, and L. R. McLain. 1973. Temperature Effect on Parr-Smolt Transformation in Steelhead Trout (Salmo Gairdneri) As Measured by Gill Sodium-Potassium Stimulated Adenosine Triphosphatase. Comparative Biochemistry and Physiology 44A:1333-1339.

Adams, B. L., W. S. Zaugg, and L. R. McLain. 1975. Inhibition of Salt Water Survival and Na-K-ATPase Elevation in Steelhead Trout (Salmo Gairdneri) by Moderate Water Temperatures. Transactions of the American Fisheries Society 104:766-769.

Baker, P. F., T. P. Speed, and F. K. Ligon. 1995. Estimating the Influence of Temperature on the Survival of Chinook Salmon Smolts (Oncorhynchus Tshawytscha) Migrating Through the Sacramento-San Joaquin River Delta of California. Canadian Journal of Fisheries and Aquatic Science 52:855-863.

Banks, J. L., L. G. Fowler, and J. W. Elliot. 1971. Effects of Rearing Temperature on Growth, Body Form, and Hematology on Fall Chinook Fingerlings. The Progressive Fish-Culturist 33:20-26.

Beckman, B. R., D. A. Larsen, C. Sharpe, B. Lee-Pawlak, C. B. Schireck, and W. W. Dickhoff. 2000. Physiological Status of Naturally Reared Juvenile Spring Chinook Salmon in the Yakima River: Seasonal Dynamics and Changes Associated With Smolting. Transactions of the American Fisheries Society 129:727-753.

Bell, M. C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. Sacramento, CA: U. S. Army Corps of Engineers, Fish Passage Development and Evaluation Program.

Berggren, T. J. and M. J. Filardo. 1993. An Analysis of Variables Influencing the Migration of Juvenile Salmonids in the Columbia River Basin. North American Journal of Fisheries Management 13:48-63.

Boles, G. L., S. M. Turek, C. C. Maxwell, and D. M. McGill. 1988. Water Temperature Effects on Chinook Salmon (*Oncorhynchus Tshawytscha*) With Emphasis on the Sacramento River: A Literature Review. California Department of Water Resources.

Boydstun, L. B. 1977. California's Steelhead Program. 26-30.

Brett, J. R. 1952. Temperature Tolerance in Young Pacific Salmon, Genus Oncorhynchus. Journal of the Fisheries Research Board of Canada 9:265-323.

Brett, J. R., W. C. Clarke, and J. E. Shelbourn. 1982. Experiments on Thermal Requirements for Growth and Food Conversion Efficiency of Juvenile Chinook

Salmon, Oncorhynchus Tshawytscha. Report # Canadian Technical Report of Fisheries and Aquatic Sciences No. 1127.

Cavallo, B., R. Kurth, J. Kindopp, A. Seesholtz, and M. Perrone. 2003. Distribution and Habitat Use of Steelhead and Other Fishes in the Lower Feather River, 1999-2001. Report # Interim Report SP-F10 Task 3A. Department of Water Resources, Division of Environmental Services.

Cech Jr., J. J. and C. A. Myrick. 2000. Growth and Thermal Biology of Feather River Steelhead Under Constant and Cyclical Temperatures. Report # Technical Completion Report- Department of Water Resources.

Code of Federal Regulations. April 1, 2001. Title 18. Section 4.51.

DFG. 1998. A Status Review of the Spring-Run Chinook Salmon (*Oncorhynchus Tshawytscha*) in the Sacramento River Drainage.

DWR. 1982. Upper Feather River Instream Flow Study.

DWR. 1983. CDWR & CDFG 1983 Agreement.

DWR. 2000. Biological Assessment- Effects of the Central Valley Project and State Water Project on Steelhead and Spring-Run Chinook Salmon.

DWR. January, 2001. Initial Information Package. Relicensing of the Oroville Facilities. Federal Energy Regulatory Commission License Project No. 2100.

DWR. 2002a. Distribution of Fishes in the Lower Feather River in Relation to Season and Temperature, 1997-2001.

DWR. 2002b. Emigration of Juvenile Chinook Salmon in the Feather River, 1998-2001.

DWR. 2002c. Study Plan Package- Presented to the Plenary Group by the Collaborative Work Groups: Land Use, Land Management and Aesthetics, Recreation and Socioeconomics, Cultural Resources, Engineering and Operations, Environmental.

EPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. Report # EPA 910-B-03-002. Seattle: Region 10 Office of Water.

Folmar, L. C., W. W. Dickhoff, C. V. W. Mahnken, and F. W. Waknitz. 1982. Stunting and Parr-Reversion During Smoltification of Coho Salmon (Oncorhynchus Kisutch). Aquaculture 28:91-104.

Greene, S. 1992. Daily Fork-Length Table From Data by Frank Fisher, California Department of Fish and Game. Sacramento: DWR, Environmental Services Department,

Hayes, D. B., C. P. Ferreri, and W. W. Taylor. 1996. Chapter No. 7. Active Fish Capture Methods *in* Fisheries Techniques. Second Edition. Murphy, B. R. and Willis, D. W. (ed.), Bethesda, Maryland: American Fisheries Society, 193-220.

Healey, M. C. 1991. Life History of Chinook Salmon (*Oncorhynchus Tshawytscha*) *in* Pacific Salmon: Life Histories. Groot, C and Margolis, L. (ed.), Vancouver, BC: UBC Press, 311-393.

Healey, T. P. 1977. The Effect of High Temperature on the Survival of Sacramento River Chinook (King) Salmon, Oncorhynchus Tshawytscha, Eggs and Fry. Report # Anadromous Fisheries Branch Administrative Report No. 79-10.

Hoar, W. S. 1976. Smolt Transformation: Evolution, Behavior, and Physiology. Journal of the Fisheries Research Board of Canada 33:1233-1252.

Hoar, W. S. 1988. The Physiology of Smolting Salmonids. Fish Physiology 11:275-343.

Kalleberg, H. 1958. Observations in a Stream Tank of Territoriality and Competition in Juvenile Salmon and Trout (Salmo Salar L. and S. Trutta L.). Institute of Freshwater Research, Drottningholm 39:55-98.

Kelley, D. W. &. A. 1988. The Roles of Feather and Nimbus Salmon and Steelhead Hatcheries and Natural Reproduction in Supporting Fall Run Chinook Salmon Populations in the Sacramento River Basin.

Marine, K. R. 1997. Effects of Elevated Water Temperature on Some Aspects of the Physiological and Ecological Performance of Juvenile Chinook Salmon (Oncorhynchus Tshawytscha): Implications for Management of California's Central Valley Salmon Stocks. University of California, Davis, 1-71.

Materna, E. 2001. Temperature Interaction- Issue Paper 4. Report # EPA-910-D-01-004. EPA.

McCullough, D.A. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. EPA Report #910-R-99-010.

McEwan, D. 2001. Central Valley Steelhead *in* Contributions to the biology of Central Valley salmonids. R.L. Brown. (ed.), CDFG, 1-43.

McEwan, D. and T. A. Jackson. 1996. Steelhead Restoration and Management Plan for California. California Department of Fish and Game.

Moyle, P. B. 2002. Inland Fishes of California. Berkeley: University of California Press,

NOAA. March 1998. Final Rule: Notice of Determination. Endangered and Threatened Species: Threatened Status for Two ESUs of Steelhead in Washington, Oregon, and California. Volume 63. 13347-13371.

NOAA. September 1999. Final Rule: Notice of Determination. Endangered and Threatened Species: Threatened Status for Two Chinook Salmon Evolutionarily Significant Units (ESUs) in California. Volume 64. 50394-50415.

Orsi, J. J. 1971. Thermal Shock and Upper Lethal Temperature Tolerances of Young King Salmon, Oncorhynchus Tshawytscha, From the Sacramento-San Joaquin River System. Report # Anadromous Fisheries Branch Administrative Report No. 71-11. California Department of Fish and Game.

Painter, R. E., L. H. Wixom, and S. N. Taylor. 1977. An Evaluation of Fish Populations and Fisheries in the Post-Oroville Project Feather River.

Pinder, L. J. and J. G. Eales. 1969. Seasonal Buoyancy Changes in Atlantic Salmon (Salmo Salar) Parr and Smolt. Journal of the Fisheries Research Board of Canada 26:2093-2100.

Rich, A. A. 1987. Water Temperatures Which Optimize Growth and Survival of the Anadromous Fishery Resources of the Lower American River.

Rich, A. A. 1997. Testimony of Alice A. Rich, Ph.D. Regarding Water Rights Applications for the Delta Wetlands Project, Proposed by Delta Wetlands Properties for Water Storage on Webb Tract, Bacon Island, Bouldin Island, and Holland Tract in Contra Costa and San Joaquin Counties. Report # S-DFG-31.

Saunders, R. L. 1965. Adjustment of Buoyancy in Young Atlantic Salmon and Brook Trout by Changes in Swimbladder Volume. Journal of the Fisheries Research Board of Canada 22:335-352.

Snider, B., R. G. Titus, and B. A. Payne. 1997. Lower American River Emigration Survey, November 1994- September 1995.

Wagner, H. H. 1974. Photoperiod and Temperature Regulation of Smolting in Steelhead Trout (Salmo Gairdneri). Canadian Journal of Zoology 52:219-234.

Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Environmental Factors Affecting Smoltification and Early Marine Survival of Anadromous Salmonids. Marine Fisheries Review 42:1-14.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California. North American Journal of Fisheries Management 18:487-521.

Zaugg, W. S. 1981. Relationships Between Smolt Indices and Migration in Controlled and Natural Environments. Seattle: University of Washington, 173-183.

Zaugg, W. S., B. L. Adams, and L. R. McLain. 1972. Steelhead Migration: Potential Temperature Effects As Indicated by Gill Adenosine Triphosphatase Activities. Science 176:415-416.

Zaugg, W. S. and H. H. Wagner. 1973. Gill ATPase Activity Related to Parr-Smolt Transformation and Migration in Steelhead Trout (Salmo Gairdneri): Influence of Photoperiod and Temperature. Comparative Biochemistry and Physiology 45B:955-965.